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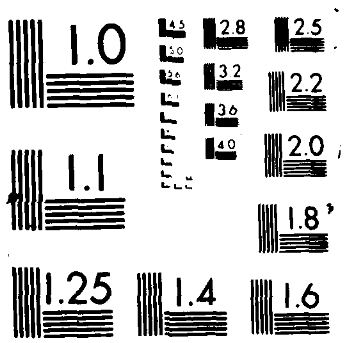
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Risk Analysis Research Program

August 1987

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The analytical review and summary critique of literature related to risk analysis was conducted for the purpose of highlighting those ideas, concepts and methods that have a bearing on conventional approaches to evaluating uncertainties of natural and technological hazards and the risks imposed by alternative solutions. The critique of the philosophical and analytical bases of risk analysis was further directed toward the specific problem of dam safety risk analysis. Dam safety is unique in that it represents an extreme situation characteristic of a low probability/high consequence event. Conventional rules of economic analysis are difficult to extrapolate and extend to such events. This analytical review was conducted as part of the Corps' Risk Analysis Research Program, managed by the Institute for Water Resources, of which the dam safety risk analysis research effort is but one part of the broader range of applications of risk analysis to Corps problems.

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As a consequence of the broader applications, a good deal of discussion deals with the generic issues of economic evaluation principles applied to problems under situations of risk and uncertainty, as defined in the "Principles and Guidelines" for water resources planning and implementation. The analytical review and critique encompassed such issues as: risk evaluation and measurement paradigms; economics of dam failure, evaluation and decision rules for proper analysis; risk cost analysis versus deterministic procedures; controversies surrounding the consideration of safety and loss-of-life valuation; consideration of secondary benefits, psychological impacts; and the role and evaluation of flood warning systems. Finally, a theoretical-conceptual model is offered for measuring disaster losses. An annotated bibliography of selected papers is also included for convenient reference.

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SOCIOECONOMIC CONSIDERATIONS IN DAM SAFETY RISK ANALYSIS

by

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A Report Submitted to the

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PREFACE

This report is one of the products of a number of related research efforts that fall under the Corps of Engineers "Risk Analysis Research Program," managed by the Institute for Water Resources (CEWRC-IWR) in conjunction with the Hydrologic Engineering (CEWRC-HEC) of the U.S. Army Corps of Engineers Water Resources Support Center (CEWRC) as part of the initiatives and directives of the Office of the Chief of Engineers. Specifically, the review of "Socioeconomic Considerations in Dam Safety Risk Analysis" is one of the products of the research plan for the dam safety risk analysis research element. However, the report supports a facet of risk considerations that underlies, and is common to, most applications of risk and uncertainty analysis in water resources planning.

The genesis of the Corps of Engineers "Risk Analysis Research Program" evolved out of a request by the Office of the Assistant Secretary of the Army for Civil Works to develop a uniform approach to evaluating dam safety by way of "...a substantial program of research which addresses the issue of dam safety assurance for existing structures as it relates to the criteria used for spillway design...." (letter of 28 Sept 1983, by Assistant Secretary of the Army William R. Gianelli). The risk analysis research effort was geared initially to focus on hydrologic and spillway-related dam safety issues.

Subsequently, the notion of extending risk and uncertainty analysis to a larger set of planning and design-oriented issues emerged, culminating in a memorandum from the Assistant Secretary of the Army for Civil Works, Mr. Robert Dawson (8 Feb 1985) asking the Chief of Engineers to "...develop a plan of action to provide guidance to FOAs on the use of risk evaluation procedures appropriate to Corps programs." This request was follwed by a plan of action for incorporating risk assessment methods into Corps planning and a training and technology transfer program. The plan consisted of a broad research program that expanded on the technical bases developed for dam safety and included a series of regional workshops on applying risk analysis to dam safety problems and in planning for flood control and navigation purposes and associated environmental consequences. A formal course in risk analysis techniques applied to planning is part of the training program.

The expanded risk analysis research program conducted at the Institute for Water Resources (CEWRC-IWR) consists of discrete work units for dam safety risk analysis; navigation planning; risk perception and communication; environmental risk analysis; and hydrologic risk analysis (conducted at the Hydrologic Engineering Center). The hydrologic and hydraulic aspects of risk analysis are conducted under the management of Arlen Feldman at CEWRC-HEC. The risk research program manager is Eugene Z. Stakhiv, assisted by Dr. David

Moser, both of the CEWRC-IWR. The work is part of the broader Water Resources Planning Studies research program conducted through the Research Division, Institute for Water Resources, which is headed by Michael R. Krouse. J.R. Hanchey is the Director of the Institute for Water Resources. The technical monitors for this research are Robert Daniel (Planning Division), Donald Duncan (Office of Policy), and Roy Huffman (Hydrologic and Hydraulics Division) of the Office of the Chief of Engineers.

ACKNOWLEDGEMENTS

In every stage of development, this report benefited from the constructive criticism of personnel within the U.S. Army Institute for Water Resources. David A. Moser, economist, thoroughly reviewed successive drafts; the valuable insights and analyses that he provided significantly improved the quality of the final report. We are especially appreciative of the contribution made by Eugene Stakhiv, program manager for risk analysis research, and contracting officer, whose participation and support skillfully guided the progression of this study.

A substantial contribution to this study was made by Dr. Dennis Mileti, professor of sociology, Colorado State University. Dr. Mileti's extensive work in the area of natural hazards warning systems greatly enhanced the research effort.

Finally, special thanks are extended to Brenda Pounder, without whom the production of this volume would not have been possible.

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I. INTRODUCTION TO THE ANALYTICAL REVIEW

The purpose of the analytical review is to critically examine the literature on risk analysis. The review was limited to those research findings which could be directly utilized for assisting in the development of procedures for dam safety risk analysis by the U.S. Corps of Engineers. Even with this restriction, the number of studies which could have been included ranged upward of one to two thousand. The count of articles pertaining to hazard warnings alone numbered several hundred. It is estimated that other risk management strategies such as floodplain zoning, insurance, and compensation would have produced an equal or greater number of citations. It became essential that a means of sorting the literature be developed which could reduce the number of annotations without losing the most important theoretical and empirical contributions. As a consequence, there was a heavy reliance placed on findings reported in survey articles, especially those written by the universally accepted experts in natural hazards.

The most important findings were analyzed to determine their consistency and applicability to the dam safety question. Here, too, decisions had to be made regarding emphasis, since not all areas could be treated in depth. An observation of the risk analysis literature showed, for example, that indirect economic impacts, warnings, and psychological effects were given only cursory treatment, despite oft-repeated claims regarding their importance. Therefore, these themes are accorded more attention in this report, resulting in three summary papers included here as Chapters III, IV, and V. Other themes were given less attention, partly because decisions regarding how they would be treated had already been made. For example, monetizing the value of a human life has been strongly discouraged by the National Research Council among others. Other hazard-mitigating measures such as insurance and zoning are given less emphasis, but several landmark pieces are annotated. This does not imply that they are any less important than warnings or structural measures; it does reflect the judgment that these subjects require a great deal more research than is possible in this limited review.

LITERATURE SELECTION CRITERIA

A checklist of recognized experts in the field of risk analysis was informally employed to begin the literature search. The most important works in the fields of risk and risk analysis, the economics of disaster (and hazards), the social and psychological impacts of disaster, warnings, and reconstruction were reviewed.

LITERATURE EVALUATION FRAMEWORK

The authors' reputations played an important role in initiating the screening process. In addition, articles were evaluated in terms of how well they integrated with other findings and whether they were based on events comparable to a dam failure. To a lesser extent the criterion of direct applicability and the potential for adoption--i.e., would it improve risk analysis--was employed. Lastly, the review focused on findings which appeared to have been recorded on more than one occasion by more than one researcher.

The critical reviews provided in Chapters II through V are the core of the evaluation and assessment framework. These chapters synthesize what is known about the socioeconomic aspects of dam safety and provide a foundation for a final assessment of research needs. The process of piecing together the findings from disparate disciplines, cutting across a number of hazards, defied simplistic schemes of categorization. Hence, each chapter reflects a slightly different orientation. The objective, however, remained the same for each, to glean reliable findings, review potential improvements in methodology, and point out shortcomings in the data. The overriding consideration throughout the analytical review was to provide the basis for the assurance that the risk assessment procedures developed by the Corps of Engineers' Institute for Water Resources reflected the most current practices and thinking in risk analysis.

The most important citations in the chapters were selected for annotation. Additional annotations were included in Appendix B for those subjects for which integrated analyses were not performed.

II. RISK: DEFINITION, EVALUATION, AND MANAGEMENT

DEFINITION OF RISK AND UNCERTAINTY

This is the broadest of categories in that "risk" can be either objective or subjective. It is simply a threat which incorporates the chance of occurrence with a set of negative consequences. Risk assessments often focus on lives lost and health risks, although of course this is a somewhat narrower definition. Property damage and indirect social and economic effects are legitimate elements of a comprehensive risk assessment. Whether a decision is best characterized as risky or as uncertain hinges on two factors, knowledge concerning the event system (rainfall, storm surge, etc.) and knowledge of outcomes produced by the events. If it is believed that the event systems exhibit knowable probability density functions and the consequences can be correctly anticipated, then the decision maker faces a game of chance, i.e., risk. If either the events or the outcomes are subject to forces which cannot be predicted (terrorist acts, consequences which have no historical precedent, etc.), then the decision maker faces uncertainty. This definition differs slightly from that found in the Principles and Guidelines, which tends to stress potential variance in the primary events. For example, "if it is known that a river will flood to a specific level on the average of once in twenty years, a situation of risk, rather than uncertainty, exists" (Water Resources Council, 1983, paragraph S1(a). It might be added that even though the natural event system may be well understood and behave according to well-known (at least as far as the hydrologist is concerned) probability distributions, the population at risk may not be so predictable. That which policy makers should be concerned about is not the flood peak coursing through a channel but its consequences in terms of loss to life and property. The triggering mechanism may be knowable and predictable, but the consequences may be uncertain.

This is of course a fine distinction, and it is unlikely that choices will be made with as much or as little information as these polar extremes suggest. Nonetheless, it is important to begin with this distinction, since much of the debate surrounding which risk evaluation and measurement paradigm is most appropriate is tied to one's beliefs regarding risk and uncertainty.

RISK EVALUATION AND MEASUREMENT PARADIGMS

The wide variety of risk analysis approaches discussed in the literature appear to flow from the following list. There are of course a number of variants, but these are the major classifications.

Technical--Multiobjective, Partitioned Risk
Economic--Benefit/Cost, Risk/Cost
Decision Analysis
Revealed Preference--Bootstrapping
Professional Judgment--Subjective and Index-Based Methods

Based on recently published bibliographies such as Covello and Abernathy (1983), it appears that the number of papers on risk-related topics has grown at an extraordinary pace over the past five years. So much is being published that it would be difficult for any single researcher to digest the annual volume of new material, let alone synthesize or review the work produced previously. To simplify the presentation, three classifications of paradigms were selected for review: professional judgment (subjective and index-based methods), economic (benefit/cost, risk/cost), and technical (multiobjective and partitioned risk). The rationale for limiting the scope to these areas is that most risk analysis controversies can be illustrated with reference to these three approaches.

OVERVIEW OF CLASSIFICATIONS

Professional Judgment

A subjective assessment of dam safety incorporates only what the engineer or dam owner considers to be most important to the case. Because of its subjective nature it may lead to good solutions but not necessarily to optimum solutions. By its nature it is difficult to document and evaluate. Index-based assessments systematically rank, rate, and/or score dams according to qualitative criteria. Although more inclusive than the subjective assessments, they too do not lend themselves to numerical comparisons. Whether the professional judgment embodied in these qualitative approaches is sufficient for the purpose of rehabilitating the dams for which the Corps is responsible is debatable. No doubt, those who support the use of such methods believe that the technical judgments involved in "solving" the dam safety problem are superior to the rigid, more esoteric, and formal alternatives which have been proposed.

Economic

The use of benefit-cost accounting (BCA) techniques is well known to the Corps, so this review is limited in scope, serving as a backdrop against which other techniques are compared. The application of economic principles to the analysis of water projects is, of course, well delineated in the Water Resources Council's Principles and Guidelines. However, the applicability of such procedures in instances where catastrophic losses might result has produced a substantial amount of controversy. The National Research Council (1983) in particular has questioned the wisdom of employing expected values in the selection of alternative damage-mitigating strategies. The extremely low probabilities of dam failure mask the risks. More important, both the probability and the consequences of failure are not well understood. As indicated above, risk is the combination of two factors, the chance of an event occurring and the resulting economic and social ramifications. The events which are, or should be, of most concern include loss of life, mental health, environmental amenities, and property, not the collapse of the dam. Yet, this point is often overlooked.

Technical

Economically Optimum Adjustment to Flood Hazards

Much has been written about the determination of economically efficient adjustments to the flood hazard, and it is not the purpose of this review to delve into these methods in great detail. However, in order to set the stage for discussing the economics of risk management, a brief review of the principles is warranted. All flood loss studies begin with a simplified depiction of the floodplain, partitioned by population at risk and elevation contours. The threat of flooding is quantified by determining the frequency of occurrence of flood peaks of different magnitudes. How the flood wave makes its way downstream is a product of a complex set of factors, including variations in flow rate, channel hydraulics, and lateral inflow. Information regarding elevations, flow, and channel characteristics is combined in a series of difference equations yielding generalized empirical flood depths for particular locations within the floodplain. Synthetic functions, which translate flood depth into damage, are applied to compute the dollar losses sustained for events of different frequencies. Expected annual flood losses are derived by integrating the resulting probability damage curves. The benefit derived from flood proofing, land use management, revised spillway design, deepening or widening the channel, etc., is measured by recomputing expected losses produced by the new conditions;[1] the difference in expected losses with and without the improvement is the expected annual benefit.

---

[1]Each adjustment influences a different part of the loss computation. Flood proofing truncates the synthetic depth damage curve at the level of protection. Flood control reservoirs shave the peaks off the discharges. Hydrologic improvements permit greater flows to move through the floodway without causing damage. Land use management reduces the population at risk or shifts the nature of floodplain activities.

A number of factors complicate the economic analyses on which floodplain management decisions are based. Productivity (and hence value) of floodplains fluctuates with time and use; pecuniary losses tend to decline exponentially with degree of protection, the most economic level of which balances both costs and losses. However, incommensurables such as loss of life and environmental amenities introduce additional problems which under some circumstances render benefit-cost accounting ineffectual.

The field of risk analysis is firmly attached to the disciplines of economics and psychology. Many of the early approaches were founded on a rational perspective of decision making which paid particular attention to benefits and costs. The field has since adopted a number of alternatives for explaining and evaluating risky decisions. Rather than assuming rationality, theorists now view the process as one fraught with vagaries and inconsistencies. It has been discovered, for example, that voluntary risks are valued differently than involuntary risks even though the probabilities may be identical (Starr, 1985). Survey research seems to indicate that the average person has a poor understanding of the likelihood of occurrence, exaggerating some events while ignoring others which are more probable (Slovic, Fischhoff, and Lichtenstein, 1982).

The following review begins with the economic approach, partly because it is still fundamentally sound and partly because it serves as a benchmark against which other methods can be contrasted. As will become evident in the pages that follow, the primary difference among the various approaches lies in how values are introduced. The index-based and subjective methods discussed briefly above rely on the technical expert. Practitioners of BCA or one of its variants (e.g., risk-cost, risk-benefit) assume that the value of safety is revealed in the marketplace. The more recent literature on multiattribute and multiobjective techniques focuses attention on the public agent, the so-called decision maker, to reflect social values by trading off one objective against another.

Duality: Net Present Value and Cost-Loss

The risk management literature tends to use terms such as residual losses and risk-cost loosely. Inevitably this has led to some confusion. The purpose of this section is to set down a simple economic framework within which these terms can be defined. From an economist's point of view it makes little difference whether a public agency attempts to maximize the present value of flood adjustments or whether it opts to minimize hazard costs. It is easy to demonstrate that both methods produce identical solutions. Assume that L_0 is the initial average annual loss expected to occur in a floodprone community. The construction of a flood control reservoir would reduce these losses in some relation to the impoundment area. L_1 is used to designate the losses which would be observed after building the dam. The average annual benefit of the project is $(L_0 - L_1)$. It is readily demonstrated that flood protection is economically efficient provided that discounted stream of losses exceeds the project's costs. It may be possible to boost the project's efficiency by altering the size of the dam in such a way that the change in cost is more than compensated by the associated reduction in expected loss. In other words, the optimum level of protection for this community is one which maximizes the difference between the discounted stream of benefits and the cost of protection. Both losses and costs are a function of the structure's height. Since L_0 is a constant, the optimum level of protection is one which balances the cost of adding an extra foot to the dam against the reduction in L_1 which such added height affords. A typical diagram of net present value is shown in Figure 1.

Minimizing the cost of the hazard (i.e., the sum of the cost of protection and residual losses) results in the same level of protection. The minimum is achieved by employing the same principle as that used to maximize net present value. Figure 2 shows how losses and costs behave in relation to dam height. It has been argued that despite this, the two methods are subtly different. At zero adjustment (i.e., no dam) in Figure 1 net value is zero, but as is observable in Figure 2, residual losses are positive. This is a minimal distinction to make, since these losses are embedded in the net present value method. In summary, minimizing the sum of costs and loss is the dual of maximizing the net present value of protection. Both yield the same optimal level of protection and, therefore, lead to the same level of residual loss.

THE ECONOMICS OF DAM FAILURE

The purpose of this part of the report is to extend risk-cost analysis to include the effects of dam failure on capital located in the floodplain. The framework presented here is a modification of the benefit-cost method first introduced by Baecher, Pate, and Neuville (1980); subsequently adopted by Moser and Stakhiv (1987) and McCann et al. (1985a,b); and then expanded by Pate-Cornell and Tagaras (1986).

The analytical framework proposed in each of these papers adjusts the expected cost of constructing a reservoir by the anticipated additional loss stemming from a failure. According to Baecher et al. the failure of a dam at some point, say t^*, results in the following costs: damage to property downstream; income losses (in the event that damaged manufacturing operations and commercial activity cannot be carried on outside the region); emergency costs; and foregone benefits as a result of losing hydropower, irrigation storage, or control of flood flows. The sum of these costs, adjusted by the probability of failure, is the cost of risk, which according to Baecher et al., should be subtracted from project net benefits.

The benefits received as a result of the dam's presence are assumed to be a constant, B, equal to the reduction in expected annual losses due to the controlled release of flood flows. If the dam does not

FIGURE 1

ECONOMICALLY OPTIMUM ADJUSTMENT TO FLOOD HAZARDS

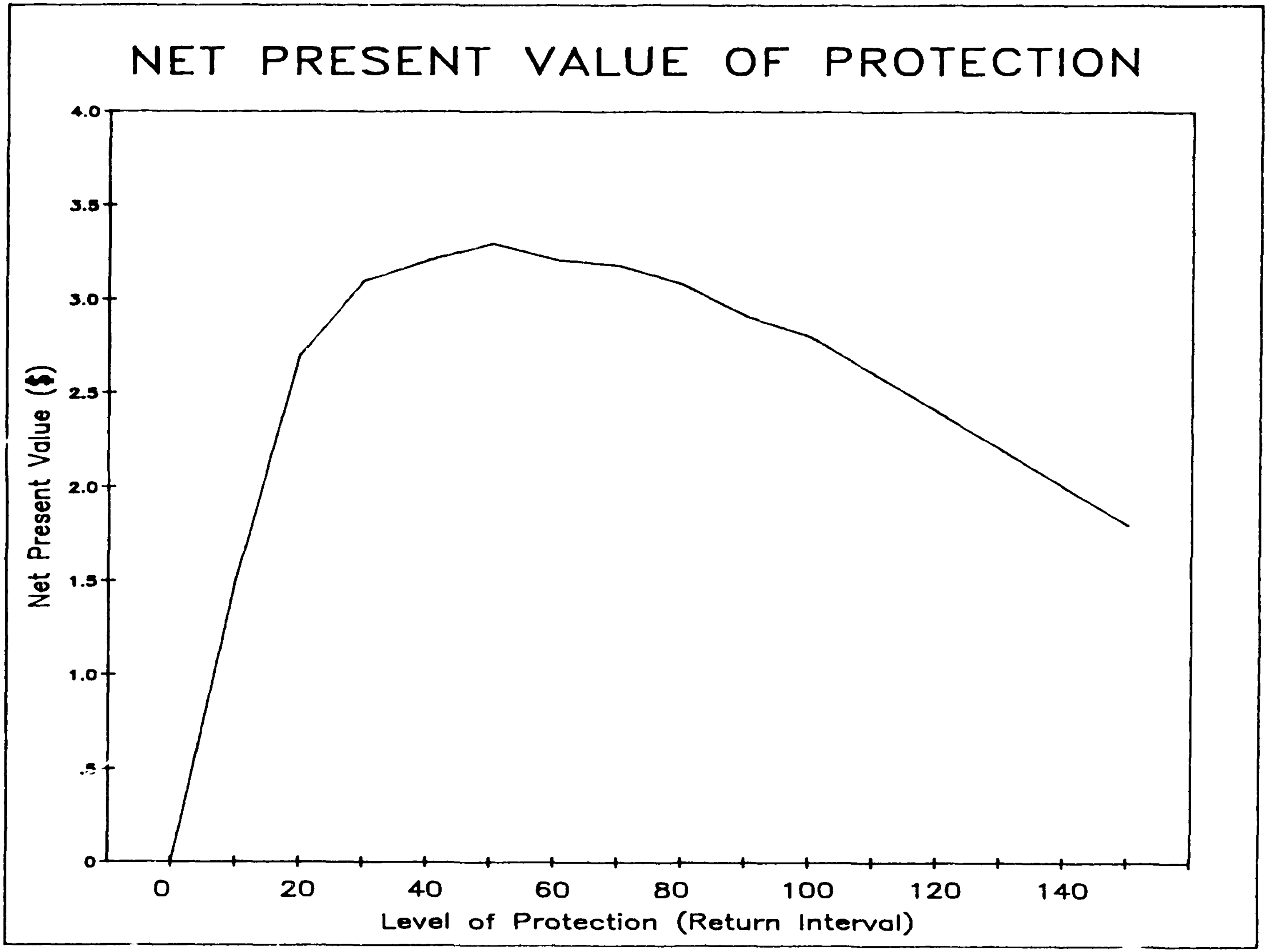
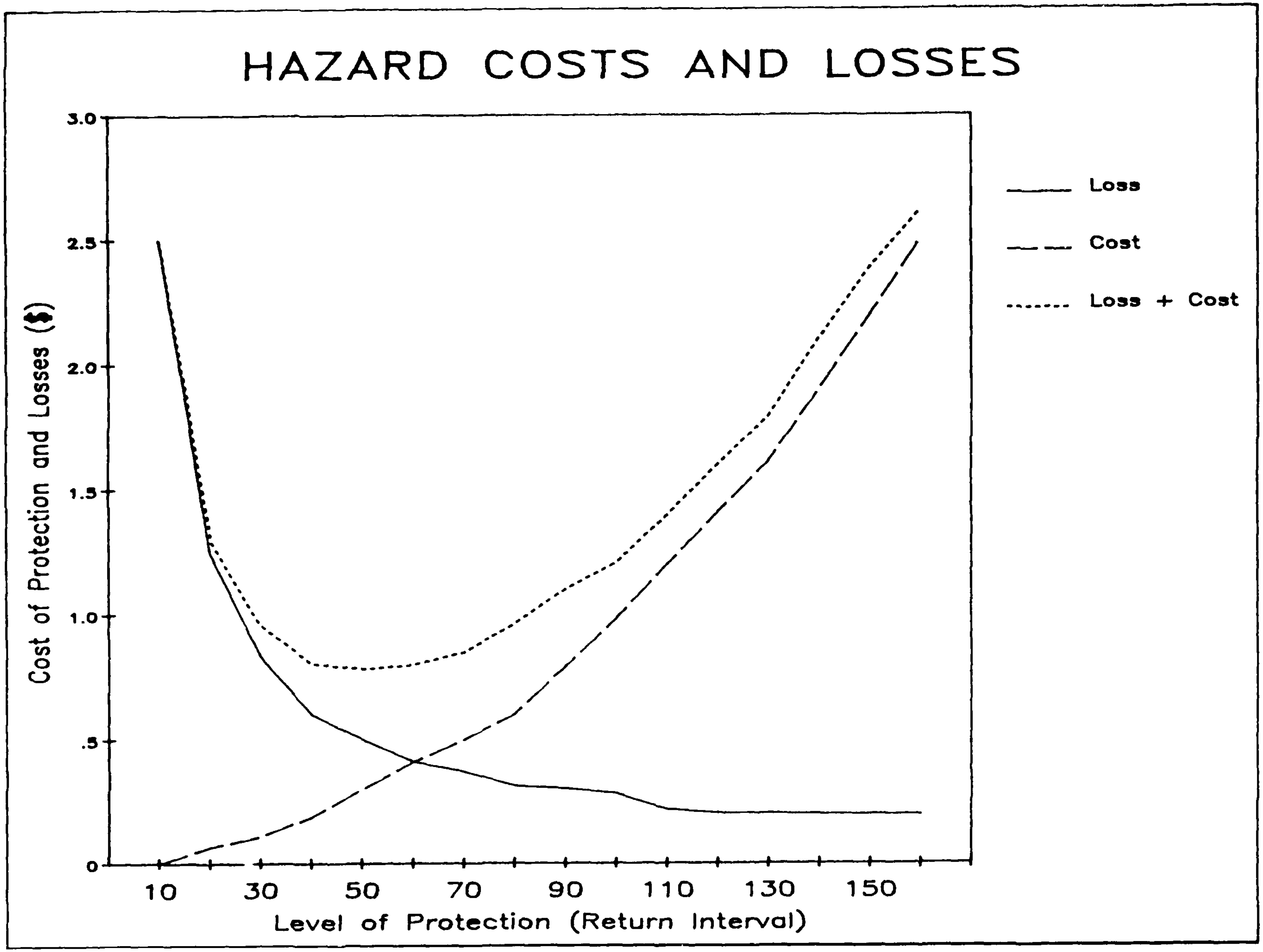


FIGURE 2

MINIMUM SUM OF COSTS AND LOSSES



fail, benefits B are received. If the dam does fail at time t*, then flood losses would return to the level experienced prior to the time when the dam was first built. This loss of flood control benefits is assumed to continue from t* to T, the planned life of the structure. This last point is most puzzling. Reduced to the simplest terms it can only be interpreted to mean that if the dam fails, the population at risk, the number of residences, and the public capital in the floodplain would be identical to that which existed prior to the collapse. Admittedly this could happen, but as will be discussed below, it may be unlikely. A combination of factors such as degree of destruction and the probable response by the Federal Flood Administration and the Federal Emergency Management Agency could constrain efforts to rebuild in hazardous locations. If reconstruction in the floodplain is not permitted, foregone flood control benefits must be zero.

A revised version of the approach proposed by Baecher et al. is developed to center attention on this question. The presentation focuses solely on flood control benefits, paying particular attention to the conditions under which the conclusions reached by Baecher et al. may not hold.

Incorporation of Dam Failure in the Evaluation of New Dams

The procedure for evaluating the economic efficiency of a proposed flood control project is well known (Water Resources Council, 1983). The cost of constructing and maintaining a flood control structure must be less than the discounted expected stream of benefits, which is the difference between the flood damage anticipated with and without the project. For flood control dams, however, the analysis typically does not consider the possibility of structure failure from flood events that exceed the design safety of the dam. The following analysis provides a theoretical framework for including the possibility of dam failure in evaluating the flood control benefits of a dam. In addition, this will be extended to provide the theoretical basis for measuring the economic effect of increasing the level of safety of an existing dam. The following notation will be used:

L_0 - average annual flood losses without the project,
L_1 - average annual flood losses with the project,
L_2 - one-time catastrophic flood losses due to dam failure,
L_3 - average annual flood losses after dam failure,
T - lifetime of project, and
PVA_T - present value of a unit annuity paid for T years with interest rate r.

The present value of flood losses without the project is:

Eq.(1) $D_0 = L_0(PVA_T)$

With the project in place, the present value of routine (without failure) flood losses declines to:

Eq.(2) $D_1 = L_1(PVA_T)$

Incorporating the possibility of failure results in defining the present value of flood losses with the project, with failure in the year t* as:

Eq.(3) $D'_1(t^*) = L_1(PVA_{t^*-1}) + L_2(1+r)^{-t^*} + L_3(PVA_T - PVA_{t^*-1})$

The first term in Eq.(3) is the present value of annual flood losses with the project up to the year of failure. The second term is the present value of the one-time catastrophic losses from failure. The third term is the present value of annual flood losses that would occur in years after failure, given the catastrophic flood losses in year t*. The key point is that in the Baecher et al. paper, it is implicitly assumed that the L_3 is equal to L_0; that is, flood losses return to the preproject level after failure. The following discussion incorporates the impacts of the probability of dam failure on project benefits and is applicable to risk-cost analysis of dam safety investments.

Assume that the probability of failure in any year t* is P_f. Thus, the probability that the project does not fail during the T years to project life is:

Eq.(4) $P[NF_1 \cap NF_2 \cap NF_3 \cap \ldots\ldots \cap NF_T] = (1-P_f)^T$

In the evaluation it is assumed that the project can only fail once. Thus, if it fails in year t*, it cannot also fail in year t*+1. Therefore, the consideration of dam failure events results in ordered n-tuples such as $[NF_1 \cap NF_2 \cap F_3 \cap \ldots\ldots \cap NF_T]$. Many of the ordered n-tuples are clearly impossible, such as $[NF_1 \cap F_2 \cap F_3 \cap \ldots\ldots \cap F_n \cap \ldots\ldots \cap F_T]$, since they would require the project to be rebuilt instantaneously after each failure. Therefore, any ordered n-tuple with more than one failure occurrence has a probability of zero (Benjamin and Cornell, 1970). In addition, the conditional probability of not failing, given that a failure has occurred, is equal to 1

Given the above considerations, expected flood losses with the project, allowing for the possibility of failure, can be written as:

Eq.(5) $$\bar{D}_1 = (1-P_f)^T (L_1)(PVA_T) + \sum_{t^*=1}^{T} P_f(1-P_f)^{t^*-1}$$

$$[L_1(PVA_{t^*-1}) + L_2(1+r)^{-t^*} + L_3(PVA_T - PVA_{t^*-1})]$$

where

$$P_f(1-P_f)^{t^*-1} = \text{probability of failure in year } t^*\text{, and}$$

$$1-(1-P_f)^T = \sum_{t^*=1}^{T} P_f(1-P_f)^{t^*-1}$$

Eq.(5) can be rewritten as:

$$\text{Eq.(6)} \quad \bar{D}_1 = L_1(PVA_T) + (L_3-L_1) \sum_{t^*=1}^{T} P_f(1-P_f)^{t^*-1}$$

$$(PVA_T-PVA_{t^*-1}) + L_2 \sum_{t^*=1}^{T} P_f(1-P_f)^{t^*-1} (1+r)^{-t^*}$$

Therefore, the expected present value of the flood control benefit from the project, allowing for the possibility of failure, can be written as

Eq.(1) minus Eq.(6) or:

$$B_0 = D_0 - \bar{D}_1 = L_0(PVA_T) - L_1(PVA_T) - (L_3-L_1) \sum_{t^*=1}^{T} P_f(1-P_f)^{t^*-1}$$

$$(PVA_T-PVA_{t^*-1}) - L_2 \sum_{t^*=1}^{T} P_f(1-P_f)^{t^*-1} (1+r)^{-t^*}$$

or rewritten as:

$$\text{Eq.(7)} \quad B_0 = (L_0-L_1)\ (PVA_T) - (L_3-L_1) \sum_{t^*=1}^{T} P_f(1-P_f)^{t^*-1} (PVA_T-PVA_{t^*-1})$$

$$- L_2 \sum_{t^*=1}^{T} P_f(1-P_f)^{t^*-1} (1+r)^{-t^*}$$

The first term on the righthand side of Eq.(7) is the difference in the present value of annual flood losses with and without the project. This represents the measure of traditionally calculated flood control benefits where the possibility of project failure is ignored. The second term is the difference in the expected present value of annual flood losses pre- and postfailure. This accounts for the fact that the postfailure annual flood losses with the project are likely to be different (i.e., smaller) than the prefailure annual flood losses. Much of the damageable property in the floodplain will likely be destroyed by the dam failure flood. The third term is as before, the expected present value of the one-time catastrophic failure flood losses.

Using the same notation, the Baecher et al. method can be shown and directly compared to Eq.(7). The present value of expected flood damage control benefits of a project in the Baecher et al. approach is the zero-failure risk, expected present value of the reduced flood damages with the project minus the risk-costs associated with the likelihood of project failure. Risk-costs stem from the loss in project benefits as well as the catastrophic flood losses in the event of failure. That is, the present value of the risk-costs from failure in year t^* is:

$$C_F(t^*) = (L_0 - L_1)\ (PVA_T - PVA_{t^*-1}) + L_2(1+r)^{-t^*}$$

Thus, the expected present value of the risk-cost following Baecher et al. Eq.(7) is:

$$\bar{C}_F = (L_0 - L_1) \sum_{t^*=1}^{T} P_f(1-P_f)^{t^*-1}\ (PVA_T - PVA_{t^*-1})$$

$$+ L_2 \sum_{t^*=1}^{T} P_f(1-P_f)^{t^*-1}\ (1+r)^{-t^*}$$

Finally, the risk-cost adjusted benefit from the project, the value of the project accounting for the probability of failure, can be written, based on Baecher et al., as:

$$\text{Eq.(8)} \quad B - \bar{C}_F = (L_0 - L_1)(PVA_T) - (L_0 - L_1) \sum_{t^*=1}^{T} P_f(1-P_f)^{t^*-1}$$

$$(PVA_T - PVA_{t^*-1}) - L_2 \sum_{t^*=1}^{T} P_f(1-P_f)^{t^*-1}\ (1+r)^{-t^*}$$

If L_0 in the second term of Eq.(8) equals L_3, then Eq.(8) would be equivalent to Eq.(7) and the Baecher et al. approach would account for the reduced postfailure annual flood losses. Note that strictly following the Baecher et al. calculation in Eq.(8) would understate the value of the project. The second term in the corrected specification of the risk-cost adjusted project benefits, Eq.(7), indicates the subtraction of a negative value, since $(L_3 - L_1)$ is negative, while the second term in Eq.(8) indicates the subtraction of a positive value.

Optimum Level of Dam Rehabilitation

The typical effect of a dam safety modification is to reduce the probability of dam failure. Some types of modifications may also reduce the likely property losses and/or loss of life in the event of a failure, although these types of modifications are not considered here. Assume that with the modification, the probability of the dam failing in any year t^* is reduced from P_f to P_{fw}. Assume also that the modification does not alter the annual flood damages with the project, L_1. Since the value of the project without the modification is B_0, the value with the modification can be rewritten as:

$$\text{Eq.(9)} \quad B_1 = (L_0 - L_1)(PVA_T) - (L_3 - L_1) \sum_{t^*=1}^{T} P_{fw}(1-P_{fw})^{t^*-1}$$

$$(PVA_T - PVA_{t^*-1}) - L_2 \sum_{t^*=1}^{T} P_{fw}(1-P_{fw})^{t^*-1} (1+r)^{-t^*}$$

The benefit from the modification which decreases the probability of failure is the difference between the value of the project with and without the modification measured as Eq.(9) minus Eq.(7) or

$$\text{Eq.(10)} \quad B_m = B_1 - B_0 = (L_3 - L_1) \sum_{t^*=1}^{T} ([P_f(1-P_f)^{t^*-1}] - [P_{fw}(1-P_{fw})^{t^*-1}])$$

$$(PVA_T - PVA_{t^*-1}) + L_2 \sum_{t^*=1}^{T} ([P_f(1-P_f)^{t^*-1}] - [P_{fw}(1-P_{fw})^{t^*-1}])(1+r)^{-t^*}$$

The first term in Eq.(10) will be negative since $L_3 < L_1$ and represents the impact of reduced postfailure flood losses on the value of the project and the benefit of a safety modification.

To show the practical effect of this correction of the Baecher et al. approach, a few numerical examples were calculated and are presented in Table 1. These examples are based on the following assumed values:

L_0 = \$ 6,000,000
L_1 = \$ 400,000
L_2 = \$900,000,000
L_3 = \$ 0
r = 8 3/4%
T = 50 years

The rows headed by Eq.(7) use the corrections presented in this section while the rows headed by Eq.(8) use the Baecher et al. formulation as written in the same notation. Table 1(a) shows the present value of flood damage reduction benefits for an unmodified project under three hypothetical annual failure probabilities: 10^{-3}, 10^{-4}, and 10^{-5}. Table 1(b) shows the present value of flood damage reduction benefits with the project modified to reduce the annual failure probability to 10^{-6}. Finally, Table 1(c) shows the difference in the flood damage reduction benefits, with and without the modification: this is the benefit from the safety improvement modification.

Table 1 shows that the different formulations result in very modest differences in the value of the flood damage reduction with the

TABLE 1

PRESENT VALUE OF FLOOD DAMAGE REDUCTION
AT INDICATED ANNUAL PROBABILITY OF FAILURE

(a) Without Modification

Annual Failure Probability Without Modification	10^{-3}	10^{-4}	10^{-5}
Eq.(7)	\$53,063,000	\$62,028,000	\$62,934,000
Eq.(8)	\$52,283,000	\$61,949,000	\$62,926,000

(b) With Modification

Annual Failure Probability With Modification	10^{-6}	10^{-6}	10^{-6}
Eq.(7)	\$63,025,000	\$63,025,000	\$63,025,000
Eq.(8)	\$63,024,000	\$63,024,000	\$63,024,000

(c) Difference in Expected Present Value of Flood Damage Reduction With and Without the Safety Modification: Failure Probability Reduced to 10^{-6}

Change in Failure Probability	10^{-3}-->10^{-6}	10^{-4}-->10^{-6}	10^{-5}-->10^{-6}
Eq.(7)	\$ 9,962,000	\$ 997,000	\$ 91,000
Eq.(8)	\$10,741,000	\$ 1,075,000	\$ 98,000

project. This disparity in the calculations translates into relatively minor differences in the expected present value of the flood damage reduction with the safety modification.

With and Without vs. Before and After

The approach just presented may be confusing at first in that it appears that a "before" and "after" approach is being recommended, rather than the "with" and "without" method called for in the Principles and Guidelines (P&G) (Water Resources Council, 1983). The situation addressed by Baecher et al. is not explicitly covered in the P&G, hence the need for an interpretation. The P&G states that losses without the project should be evaluated given the land use and related conditions likely to occur under existing improvements, laws, and policies. With-project losses are to be determined based on the most likely future set of conditions. It only seems appropriate to view with-project failure in the same light. Therefore, in following the P&G a plausible postproject and hence a postdisaster future must be selected. The question regarding the prospects for rebuilding damaged industrial and commercial structures cannot be avoided. There are compelling reasons for considering a scenario in which rebuilding in the floodplain is precluded.

What are the Prospects of Surviving the Dam Failure and Rebuilding?

For a number of reasons it appears that rebuilding after a dam break will proceed slowly if at all. First, the availability of low interest Small Business Administration disaster loans would be tied to decisions to relocate outside the 100-year floodplain. Second, the continued availability of federally subsidized flood insurance hinges on the active involvement of local planning and zoning agencies in minimizing the extent of floodplain encroachment. Third, the economics of floodplain occupancy and protection may have changed as a result of a dam's failure. Truly catastrophic losses would severely reduce or even eliminate the prospects of repairing the dam; the aftermath level of flood control benefits would not justify the expense of reconstruction. Without the protection afforded by the dam, property owners might rethink the relative merits of on- and off-floodplain building sites.

The extent to which any of these factors play a role in shaping postfailure growth in floodplain occupancy is linked directly to the nature of the losses which a dam break might produce. There is no agreement on this point, although most descriptions imply heavy damage. For example, The Interim Procedures for Evaluating Modifications of Existing Dams Related to Hydrologic Deficiency states, "Downstream peak flows, total volume and therefore consequences may differ from the different failure modes. . ." (p. III-3). The document goes on to conclude, "A failure of the dam will result in at least a short-term (3-5 year) loss of some or all of the beneficial outputs produced by the dam/reservoir. These include flood control. . . . The downstream consequences of an embankment failure are likely to be severe. Large areas are likely to be inundated that had never experienced flooding since the settlement of the region. In addition, the extent of the damage within the 'normally' floodprone area will be more severe due to high flow velocities and large sediment load from a dam breach" (U.S. Army Engineer Institute for Water Resources, 1986, p. III-3, emphasis added).

To rely on an implausible scenario, such as instantaneous rebuilding of residential and commercial properties, to meet the letter but not the intent of the P&G would lead to inefficient allocation of resources. There are times, this being one, when the with and without principle must incorporate a glimpse into the before and after.

The Economics of Warnings

The procedure developed above implied the availability of a single adjustment, elevating the dam. There are, of course, a number of ways in which the problem of flood losses can be attacked, and in all likelihood a combination of measures will ultimately prove to be most effective. A more detailed discussion of warning systems is presented in Chapter V. Howe and Cochrane (1976) demonstrate that the optimum adjustment to a hazard is one which blends short-run protective measures, triggered by weather forecasts, with longer-run adjustments tied to the climate. The costs and effectiveness of both sets of options, including type I and type II errors incurred in the use of forecasts, combine to determine the most efficient mix of protection. Pate (1985) and Krzysztofowicz and Davis (1983) employ a similar strategy in the evaluation of warning systems in a water resource context.

The inclusion of warnings as an option in an economic framework is not as challenging conceptually as it is empirically. The likelihood of detecting a hazard and disseminating effective instructions about evacuation to the threatened populations is, as will be shown below, highly variable.

The Theoretical Effect of Self-Insurance on Optimum Protection

It is possible that property owners correctly anticipate the stream of losses that would be incurred within the floodplain. If so, the cost of the hazard would be reflected in property values. This complicates the task of optimizing the level of protection. The lower cost of ownership (rental value) can be viewed as a benefit to the occupant. To the extent that real estate markets are functioning properly and individuals are well informed, this reduction in rental costs should approximate the anticipated losses. From the standpoint of the public agency, federal projects which diminish flood risks would simply result in a redistribution of wealth from the population at large to the floodplain occupants.

A number of studies have attempted to determine the extent to which self-insurance occurs. The extent to which risks are internalized by decision makers has plagued economists for the better part of the last decade. For example, does failure to purchase federal flood insurance mean that people do not behave rationally, i.e., they do not attempt to maximize expected utility? This question is of more than academic concern, for if it could be demonstrated that risks are not reflected in behavior, then market data could prove to be an unreliable guide for evaluating risks.

Do Households and Businesses Self-Insure?

A number of studies have been conducted to determine the extent to which risk is discounted by decision makers. Surveys such as that conducted by Kunreuther et al. (1978) suggest that interpretation of risk is highly subjective, depending on the way in which a gamble is portrayed and on the experiences of the decision maker. "Taken together these findings suggest that most individuals do not collect enough data to evaluate the costs and benefits of alternative courses of action regarding protection from low probability events" (p. 240). As a result, it is difficult to conclude that markets accurately reflect the probabilities and outcomes of hazardous situations.

This conclusion has been recently challenged by Brookshire et al. (1985), who estimated a hedonic price index for structures situated inside and outside of earthquake special study zones. Their results show a statistically significant difference in selling price between the two areas, amounting to approximately 6 percent of market value. A similar study, conducted by Cochrane (1985) of landslide hazard areas in Vail and Aspen, Colorado, resulted in no detectable difference in market values. If anything, the landslide zones tended to appreciate more rapidly than the nonhazard zones. This may be in part due to the positive correlation between slope and nearness to ski lifts, an observation also made by Brookshire et al.

It appears that if self-insurance is occurring, it is a minor consideration, particularly in the context of probable maximum flood (PMF). It is doubtful whether a price differential would be observed downstream of high-hazard dams; the probability of failure is too low, the inundation maps are not available for a majority of sites, and it may be impossible to isolate the effects of flood hazard from the positive aspects of living proximate to a large reservoir.

Risk-Cost as a Means of Addressing the Value-of-Life Question

Baecher et al. (1980) show how statistical lives saved can be valued. Rather than starting with a dollar amount and adding this to the benefits of enhancing dam safety, they divide the projects net benefits by the number of fatalities anticipated as a result of failure. The resultant measure is the net discounted benefit foregone per statistical life lost over the life of the structure. Their approach addresses the valuation question by transferring responsibility to the political level, where ultimate judgments regarding the social acceptability of such sacrifices are made.

Other Approaches for Assessing the Value of Saving Lives

Despite the unpleasant nature of the valuation question, economists have nonetheless attempted a number of approaches for assigning a dollar amount to a statistical life lost. The conventional measure of how much society values a safer environment is its willingness to pay to enhance the probability of survival. The theoretical justification for this approach is clear, if not operational. That is, perfectly informed individuals are the best judges as to how much of their income should be devoted to protective, life-preserving options. In technical terms, individuals at risk are assumed to strike a balance between the satisfaction gained from a prolonged life and the expenditures required to achieve added protection. The framework is simple yet deceptively powerful (see Linnerooth, 1979).

The argument proceeds as follows. Assume that an individual (a bachelor without bequest motive) is at risk from the failure of a high-hazard dam. Assume, too, that this individual receives satisfaction from the consumption of goods alone. The joy of simply living, the beauty of sunsets, do not enter the utility function. Providing that he understands the probability of failure and its consequence, which we will assume to be death, a utility-optimizing individual should be willing to entertain a potential trade-off, wealth for safety. Let P_0 be the probability of failure. The expected utility received from consumption over the individual's life cycle would be

Eq.(11) $E(U_L) = P_0\, U(C)$

U(C) is the utility derived from consumption. The total differential of this expression is

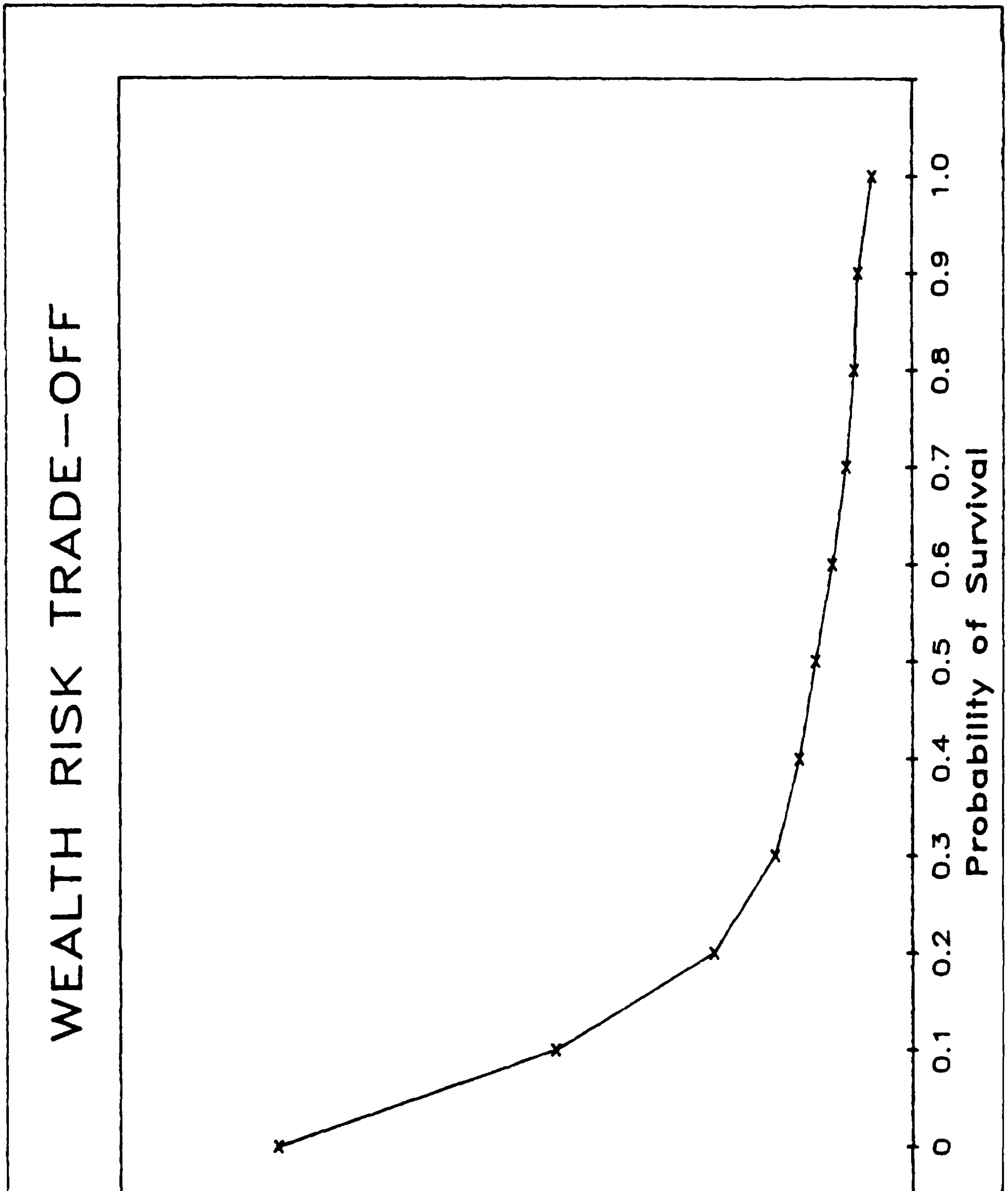
Eq.(12) $\delta[E(U_L)] = U(C)\ \delta P + P_0\ U^1(C)\delta C$

$U^1(C)$ is the marginal utility of an additional unit of consumption. The righthand side of the equation is comprised of two terms, the amount that expected lifetime utility would change due to a shift in the probability of survival (leftmost) and due to income spent on consumption (rightmost). Setting the change in expected utility equal to zero and rearranging terms, we see that the willingness to trade off safety and wealth (i.e., discounted income) is nonlinear.

Eq.(13) $\delta C/\delta P = U(C)/[P_0\ U^1(C)]$

Given that the individual in question is concerned for himself alone and does not save, consumption must be equivalent to income and subsequently to wealth. Figure 3 shows this relationship. Several

FIGURE 3


WEALTH RISK TRADE-OFF
Wealth (in Monetary Units)
0
2
4
6
8
10
12
14
16
18
20
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Probability of Survival

important observations can be made with reference to the trade-off implied by Figure 3. First, the spotlight is on the individual's willingness to pay to improve safety. The value of a statistical life is embedded in this valuation, but it is not the central issue. Second, the shape of the function resolves a paradox, that is, although the individual places an infinite value on his own life, he is willing to accept compensation for incurring additional risk. As a direct result, the higher the chances of survival, the lower the value attached to additional safety. For example, an individual might pay $100 to purchase a smoke detector which reduces the probability of perishing in a fire from .002 to .001. However, this same individual would be willing to pay less than $100 to reduce the probability of death from .008 to .007. Third, the framework provides a rationale for conducting empirical studies of risk. The trade-off depicted in Figure 3 can be measured. Theoretically, willingness to spend on life-prolonging measures such as smoke alarms and homes in unpolluted neighborhoods should be observable, as are wage rate differentials for occupations exposing workers to different degrees of risk. Even government expenditures on hazard reduction reflect how the political sphere has internalized such trade-offs.[2] Fourth, the use of willingness to pay is consistent with the requirements of BCA; it focuses attention on the choice process which could enhance welfare (lead to a Pareto improvement). Fifth, it provides a pecuniary index of safety which can be combined with other monetary measures, such as damage, lost income, etc. Sixth, willingness to trade off safety for wealth is a function of age and income and, most important, the perception of risk.

Problems with This Simple Theoretical Base

A number of the simplifying assumptions used to produce the model have been subjected to scrutiny, producing a wide variety of variants to the main theme. First and most obvious, life may be inherently pleasurable for some and unbearable for others. This outlook may be, and in many cases is, unrelated to income. If on balance there is a positive residual, then earnings may be a poor reflection of the utility of simply being alive. By including "joy of life" as a separate argument in the utility function, Linnerooth (1979) shows that discounted lifetime consumption (i.e., wealth) understates an individual's willingness to pay for safety. As a result, Linnerooth concludes that "in the absence of available data on personal demand for increased survival probability it is impossible to determine the relationship between willingness-to-pay and the human-capital approaches to placing a value on human life" (p. 52).

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[2]If the federal budget is to be balanced, additional spending on risk reduction must be accompanied by either an increase in taxes or a reduction in spending on other activities.

It is equally difficult to believe that individuals at risk make safety decisions without concern for others. Obvious questions regarding interdependent utility functions and other externalities spring to mind. It is not clear, however, how such concerns affect willingness to pay. The marginal utility of money or wealth may not be zero at death, as is implied in the above simple framework (Jones-Lee, 1976). The problem here is not knowing how much of this interdependence is accounted for in work, leisure, and savings decisions. It should also be noted that term life insurance could provide required compensation to survivors.

These criticisms are but a sample of what the literature has to offer. As may already be evident, the theoretical foundation for a wealth risk trade-off is shaky at best. Yet few realistic alternatives have been developed. At one extreme Broome (1978) argues that in assessing projects which involve risk to life, the analyst cannot hide behind the veil of statistical lives; he/she must proceed as if they had full information as to whose life was jeopardized. As Mishan (1971) points out this is equivalent to assigning an infinite cost to most projects, thereby foreclosing all chances of adoption. We can only assume that Broome would argue that all new dams would have to be riskless (meet the PMF) and that all hydrologically deficient dams would have to be rehabilitated. It appears that for lack of a more acceptable framework, and in spite of numerous criticisms leveled at willingness to pay, practitioners and theoreticians have reluctantly stuck with it. Indeed, much of the empirical work on this question is grounded in the wealth risk trade-off. The human capital approach (Buehler, 1975) is of course a surrogate for lifetime consumption and wealth. Expenditures on safety measures are a direct market test of willingness to pay, while contingent valuation methods (CVM) elicit trade-offs through experimental designs (Acton, 1973). Differential wage rates for occupations with varying exposures to death and injury reveal something about the compensation required to induce risk taking (Thaler and Rosen, 1975). As will be shown below, there is no shortage of empirical research on these topics; it is disquieting, however, to view the wide disparity of results which have been published. See Tables 2 and 3. Why has this been the case?

Reasons for Variation in the Values

The variation shown in Tables 2 and 3 can be traced to a number of factors including differences between the subjective and objective assessments of the probability of survival; the nature of risk, whether it is voluntary or involuntary; expectations regarding compensation in the event of disaster; and methodological problems incurred in isolating risk from everything else. Each of the approaches mentioned above is plagued by one or more of these problems. The following are what we believe to be the most important explanations for the disparity in values reported in the literature.

TABLE 2

SOME EVIDENCE ON THE VALUE OF LIFE

	Dollars in Thousands
1. Hazard pay	
Premium miners accept to work underground	34-159
Test pilot	161
2. Medical expenditures	
Kidney transplant	72
Dialysis in hospital	270
Dialysis at home	99
3. Valuation of the cost of disease	75
4. Valuation of the cost of airline accidents	472
5. Traffic safety	
Recommended for cost-benefit analysis by the National Safety Council	137.5
Value of life in a cost-benefit study of highways	100
6. Military decision making	
Instructions to pilots on when to crash-land planes	270
Decision to produce a special ejector seat in a jet plane	4,500

Source: Usher (1973)

TABLE 3

SOME RECENT VALUE-OF-LIFE ESTIMATES

Source of Evidence	Authors	Value of Life, 1980 U.S. Dollars, Thousands*	Associated Mortality Risk
	Implicit Values From Labor Market Activity		
Blue-collar workers in manufacturing and construction	Dillingham (1979)	378	10^{-4}
Workers in risky occupations	Thaler and Rosen (1976)	494	10^{-3}
Males in manufacturing industries	Smith (1976)	2,785	10^{-4}
Blue-collar workers	Viscusi (1979)	2,820	10^{-4}
	Implicit Values From Consumption Activity		
Residential housing market	Portney (1981)	180	10^{-4}
Residential smoke alarms	Dardis (1980)	351	10^{-5}
Highway speed	Ghosh et al. (1975)	419	10^{-4}
Auto seat-belt use	Blomquist (1979)	466	10^{-4}
	Contingent Values		
Air travel	Frankel (1979)	57	10^{-3}
		3,372	10^{-6}
	Jones-Lee (1976)	10,120	10^{-6}
Heart attack prevention	Acton (1973)	59	2×10^{-6}
		91	10^{-3}
Nuclear power	Mulligan (1977)	428	10^{-4}
		3,576	10^{-5}
Reducing cancer mortality	Landefeld (1979)	1,632	10^{-4}
	Modified Human Capital		
U.S. population by sex and age group	Landefeld and Seskin (1981)	898	
Neoplasm (cancer)	Arthur (1981)	185	4×10^{-2}
	Implied Policy Values		
Trihalomethanes in water	U.S. EPA (1979)	227	status quo to 100 mg/L
Arsenic	Council on Wage and Price Stability (1976)	6,800	approximately 10^{-3}
Vinyl chloride	Perry and Outlaw (1978)	9,450	approximately 2×10^{-5}

Source: Sharefkin et al. (1984), p. 1,778.

Occupational risk studies need to recognize that natural selection may be at work. Zeckhauser (1975, p. 436) points out that "the people who are assuming the risks are those who value them the least in relation to the benefits they get for risking them. They may be the poor, they may be the people whose probability assessments are most in error, they may be the people who legitimately have the lowest probability of being injured, they may be the people who will die soon anyway, or they may be the people who value their own lives the least highly." If Zeckhauser is right, then the measured willingness to pay for safety may be lower for those working in these risky occupations than for the population as a whole.

Occupational risk may be correlated with a number of other qualities which contribute to wage differentials. Whether the statistical difference in pay is attributable to risk rather than to another quality is debatable. Since labor rates are influenced by both demand and supply,[3] identification could also pose problems. The question is made more complex by the fact that worker flexibility erodes with seniority. For individuals who have been associated with a company for any period of time, more is at stake than wage income. Retirement, job security, and other fringe benefits may be in jeopardy in moving from one occupation to another in response to changes in perceived risk.

Workplace risk is voluntary. It is questionable whether the values obtained in these studies can be transferred to situations in which threat to life is involuntary. This raises interesting questions regarding floodplain occupancy. Is the population at risk there voluntarily? The answer to this question rests on their subjective interpretation of the risks.

Much has been made of the problems associated with the use of the contingent valuation method (discussed below). It is well known that willingness to pay can be highly influenced by how questions are framed and sequenced. Whether deliberately exploited or not, it is probably true (although to our knowledge untested) that some of these same biases are at work in the marketplace. How wage offers are communicated and risks explained could play a role in determining wage scales.

Obtaining valid estimates of willingness to pay from observed consumer behavior is equally challenging. For example, can the difference in residential property values within and outside the

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[3]Both the supply and demand for labor contain a discount for risk. The supply of labor is directly affected by worker attitude and the insurance requirements. The demand for labor could shift as capital is substituted for labor exposed to risk or as additional safety devices are mandated by law.

floodplain be attributed to potential loss of life? There are, of course, at least two losses at consider, property and life. Sorting out one from the other is virtually impossible. The low probability assumed for dam failures may make risk impossible to detect in a statistical study which employs a hedonic price index. If, for example, the probability of failure is .0001 and the loss ratio is .9, the loss expected for a $100,000 house is a mere $100, a value much lower than the variance around the dummy variable reflecting risk. Similar problems have crept into studies of health-related effects of pollution. The hedonic pricing study conducted by Portney (1981) could rule out risk's complementarity and substitutability with other amenities.

Lastly, survey research designed to elicit trade-offs directly from decision makers has run into numerous difficulties triggering claims and counterclaims regarding appropriate strategy. The contingent value method (CVM) can be summarized quite easily: "If this happens what would you be willing to pay?" Randall, Hoehn, and Brookshire (1983, p. 637) provide a more comprehensive definition. "Contingent valuation devices involve asking individuals, in survey or experimental settings, to reveal their personal valuations of increments (or decrements) in unpriced goods by using contingent markets. These markets define the good or amenity of interest, the status quo level of provision and the offered increment or decrement therein, the institutional structure under which the good is to be provided, the method of payment, and implicitly (or explicitly) the decision rule which determines whether to implement the offered program. Contingent markets are highly structured to confront respondents with a well-defined situation and to elicit a circumstantial choice contingent upon the occurrence of the posited situation."

The key elements of this definition which relates to the valuation of safety and multiple objectives is the precise definition of the contingent situation (in this case the consequences of the dam failure) and their accurate interpretation by the decision maker. Practitioners of CVM have unearthed a number of problems which could lead to biased results. The following are the more commonly reported sources of error.

Vehicle bias--the mode of payment may skew results. People who are adverse to paying taxes may react negatively to this and understate his/her willingness to pay to avert a disaster. Sequencing bias--the order in which information is provided to the respondent can alter the bid. The quality and quantity of information can also influence responses. Willingness to Pay and Willingness to Accept--theoretically they should produce the same results (Willig, 1976), based on the assumption that the income effects will be small. In practice, however, there appears to be a difference between the two. On average, willingness to accept is three to five times greater than willingness to pay (Cummings, Brookshire and Schulze, 1986, p. 35). Framing bias--Bishop and Heberlein (1979) have suggested that measures derived by the CVM method may reflect individual attitudes vis-a-vis an environmental commodity as opposed to an intended behavior. Question: Does attitude help predict intended behavior, does intended behavior predict actual behavior? Can the subject of a CVM interview place meaningful values on commodities with which they are unfamiliar? Incentives--lack of incentives for an accurate reply may lead to low quality responses. In concert with questions which are believed to be unfamiliar or involve unpleasant situations (disasters), this lack of incentive could lead to nonsensical results (Bishop and Heberlein, 1979). Strategic bias and the free rider problem--answers could be tailored to manipulate the chances of receiving benefits.

Shortcomings of the Risk-Cost and BCA Approaches

Despite the significant gains that have occurred over the past decade in refining survey instruments and honing theoretical constructs, the essential ingredients for incorporating risk into BCA are still clearly lacking. It appears that although market data provide a useful glimpse of what society at large is willing to tolerate in terms of risks, it is still no more than a glimpse. The use of expected values in these analyses tends to obscure the losses that result when the less probable events materialize. Perhaps the primary criticism that has been leveled at risk-cost methods is the lack of appreciation for the process of valuation. It is clear from the work of Starr (1985) and others that risk wealth trade-offs may be nonlinear. Hence, the social losses may not be a simple additive adjustment to project net benefits as Baecher et al. suggest. These concerns have led to the development of alternative technical means (multiobjective and partitioned risk) of deriving an optimum strategy for those situations involving more than economic efficiency.

Multiobjective Techniques

Multiobjective techniques (Haimes and Hall, 1974) were intended to supplant BCA in instances where competing yet incommensurable objectives were at stake. For example, a reservoir designed to produce hydroelectric power, flood control benefits, recreation, and municipal water supplies could not achieve maximum safety and economic efficiency simultaneously. One might observe a set of solutions which tends to favor one objective at the expense of another; for example, favoring minimum flood-hazard costs at the expense of hydropower and water supply. Multiobjective techniques produce an efficient set of objectives which can be manipulated according to the preferences expressed by one or more public decision makers. This approach is purported to be superior to BCA in that the public decision maker "is better informed and can make the trade-offs in a way which reflects social values." Although proponents of multiobjective techniques have taken great care to distinguish it from other methods, they have not carefully compared it to BCA or investigated the limitations inherent in the trade-off process, a point to which we now turn.

Assume that the individuals are informed about the probability of disaster and the implications for their own loss of life. Assume, too, that they opt to trade off income (wealth) according to the function shown in Figure 3. If they were asked to maximize their own utility according to the surrogate worth trade-off method proposed by Haimes and Hall (1974), what combination of efficiency and safety would they choose? Recall from the framework develcped above that such an individual would balance the satisfaction received from prolonging his/her life against the loss of consumer utility. A dollar spent on safety diminishes the disposable income available for consumer items. How is this trade-off related to the surrogate worth trade-off? Haimes and Hall argue that multiobjective analysis is required in the evaluation of water resource problems, since two or more of the objectives may not be commensurable. It is this lack of commensurability that leads to the logical conclusion that no single optimum decision can exist. Viewed in two dimensions, one can either maximize safety or maximize economic efficiency but not both.

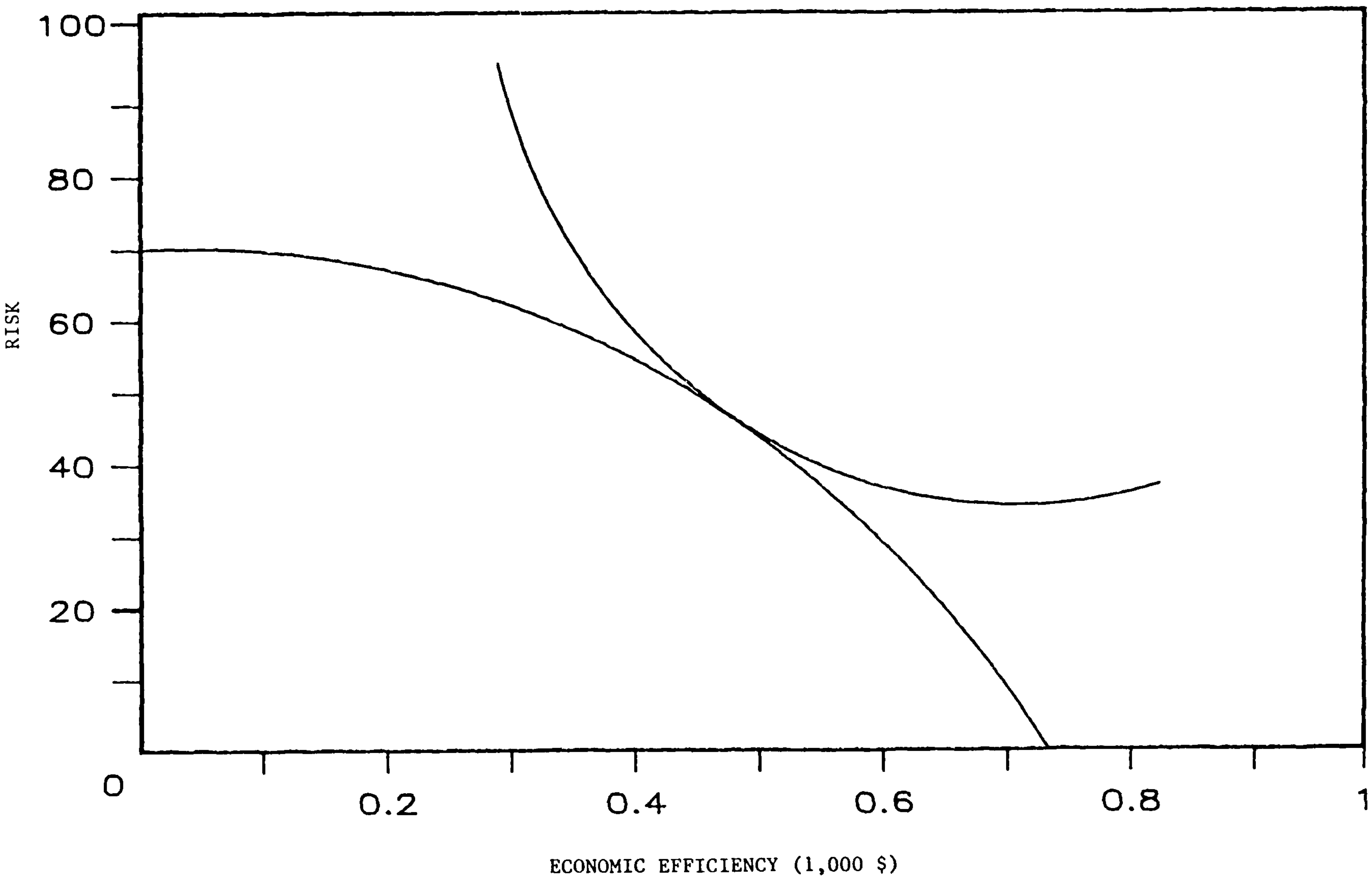
The Haimes and Hall approach is quite ingenious. They borrow the principles of consumer theory and apply them to public choice. First, they identify the attributes of the decision problem, safety, recreational values, economic efficiency, environmental protection, etc. Next, they determine a set of noninferior solutions, i.e., combinations of attributes which are most efficient in a Pareto sense. More of one attribute could not be obtained without giving up some of another. Such a procedure produces a set of shadow prices for each objective (which is also a constraint for all other objectives). Once a Pareto solution has been achieved, the worth of any one objective can be evaluated in terms of a trade-off, how much of one must be sacrificed to boost the achievement of another.

Applying this approach to dam safety we would see the trade-offs (the value of the Lagrangian multipliers in Haimes and Hall) in terms of probability of collapse (and subsequent loss of life) vs. economic efficiency. The slope of the resultant noninferior set provides the public decision maker the information to make trade-offs, hopefully reflecting the preferences and values of the individuals he/she represents. Given a two-dimensional problem, such as that just posed, the shadow price of safety can be measured in dollars, since efficiency is the companion objective which must be sacrificed. (See Figure 4.) According to Haimes and Hall the optimum mix of objectives is one which reflects social preferences and values. To the extent that the public agent fully understands the information presented and is able to accurately interpret the community's values, the optimum solution can be achieved. This is done by simply asking the public agent to make the necessary trade-offs in light of given information about the noninferior set. This description does not do justice to the elegance of the Haimes and Hall method. But it does capture its essence.

The description has been kept simple for the purpose of isolating the fundamental differences between those who propose to sweep multiple objectives into a single scaler using BCA and those like Haimes and Hall who wish to separate the objectives and value them independently. In the simplest of situations, they are at least identical. If the

FIGURE 4

SURROGATE WORTH TRADE-OFF
IN TWO DIMENSIONS



public agent is doing his/her job properly the willingness to trade-off safety for project net benefits should be equivalent to their constituent's desire to do the same. Their trade-off was shown to be measurable in the marketplace. If the trade-off function shown in Figure 3 is applied to the probabilities shown in Figure 4, the safety axis would be measurable in expected dollar terms, thereby permitting the public agent to opt for a unique solution without guessing or interpreting the values of those whom the project is designed to affect. The noninferior set would be in dollar terms and the trade-off function would be linear with a slope of minus one. A dollar is traded for a dollar. For that matter two dimensions would no longer be needed. The value of safety could be superimposed on the national economic development (NED) axis yielding a single measure of benefit.

To be sure, many who advocate the use of multiobjective techniques will object to the simpleminded equivalence just suggested. First, they might argue that individuals at risk may not fully appreciate the risks they face. A public agent might be better informed. Second, the risks imposed by the water project may not be voluntary and, therefore, the values which have been derived from voluntary exchanges (labor market and consumer studies) may understate the consequences. These are of course valid criticisms, and they indeed sharpen the debate by focusing it on the proper issues. Whether multiobjective or BCA is used may be of lesser consequence than the accuracy of the images portrayed and the evaluation that institutional arrangements foster in eliciting values. This is not to say that the multiobjective is without flaws. No doubt it is possible, although at times difficult, to get decision makers to make trade-offs (Sung et al., 1984). What the trade-off reflects is not as clear cut. Either it reflects concern about personal risk job security or it reflects the same problems and biases which plague contingent valuation methods. Skepticism with regard to the ability of public agents to provide the information required by the multiobjective approach has been clearly and succinctly stated by Cohon, Revelle, and Palmer (1981, p. 127): "Public decision making processes are not well understood. We do know, however, that they are dynamic and usually characterized by many decision makers. Furthermore all of the decision makers may be unknown to the analyst, and, if they are known, they may be relatively inaccessible. This raises the following questions: Whose preferences should be used? How should differences among many sets of preferences be recognized? How should unknown or unknowable preferences be accounted for? How should changing preferences be represented? These are difficult questions that have not been answered. Yet, it seems to us that they must be answered before preference-oriented techniques can be used to support real public decisions."

Index-based methods and standards are weak on values and strong on the technical trade-off. It seems, therefore, that under a restrictive set of conditions surrogate worth trade-off and benefit-cost, using market data regarding willingness to pay for safety, yield identical results. One is just a mirror of the other.

SUMMARY

Skepticism about the utility of benefit-cost in evaluating low-probability events is understandable. Risk-cost analyses promoted by researchers at MIT (primarily Krzysztofowicz) and Stanford (Pate-Cornell) attempt to include the cost of dam failure in traditional benefit-cost procedures. However, they must rely, at least implicitly, on valuing life, the effectiveness of warnings, the damage functions, and the event probabilities. Despite these problems, Baecher et al. (1980), Pate-Cornell (1984), and Krzysztofowicz and Davis (1983) have produced a series of studies which apply the approach.

It appears, for the reasons cited above, that more sophisticated risk management methodologies (such as chance-constrained programming) are unlikely to lead to improved decisions. What is needed instead is a simpler set of guidelines for practitioners in the field, guidelines grounded in a better understanding of a broadly defined set of risks (including the social and economic consequences of dam failure). Clearly catchwords such as "acceptable level of risk" have served to bring dam safety into greater focus. However, continued refinements of terminology and methodology seem at this point to yield diminishing returns. A fresh look at alternative risk management strategies using simple tools such as cost-effectiveness analysis appears to be warranted.

Despite the large investment in risk analysis that has already been made, there are several areas where the state of the art exceeds that which risk analysts have adopted. This is true particularly in the fields of regional economics, warnings, and psychological effects. The following chapters provide a more elaborate review of these areas than is typically found in risk assessments.

III. ISSUES AND CONTROVERSIES REGARDING THE SECONDARY EFFECTS OF CATASTROPHE

A BRIEF INTRODUCTION TO THE ISSUES AND CONTROVERSIES

A number of studies have been funded to determine the extent to which disasters create employment effects (Cochrane et al., 1974; Friesma et al., 1979; Wright et al., 1979; Roberts, Milliman, Ellson, 1982). It is ironic that federal agencies would support such efforts, given the prevailing convention which tends to downplay such effects. The P&G, for example, states that "The loss of income by commercial, industrial, and other business firms is difficult to measure, because of the complexity involved in determining whether the loss is recovered by the firm at another location or at a later time. . . . The loss of income because of idle labor may be measured from the point of view of the firm or the household, but care must be taken to avoid double counting. . . unemployment compensation and other transfer payments to idle labor are not income from a NED perspective" (Water Resources Council, 1983, paragraph 2.4.15(a). Based on the review of the literature, there appears to be little consensus as to what constitutes secondary losses, how they could be measured, and the precise conditions under which the prevention of regional income effects can be claimed as NED benefits.

The objectives of this chapter are to (1) establish a theoretical framework for differentiating primary from secondary losses;[4] (2) utilize the framework to establish the conditions under which disasters could produce significant economic disruption (from both a regional and national perspective); (3) critically review the research that has been conducted on the subject of economic shocks; and (4) develop simple and inexpensive guidelines for estimating the potential industrial and commercial dislocations resulting from the catastrophic failure of a high-hazard dam.

It is clear that the problem of secondary loss has been the subject of considerable study, yet surprisingly few theoretical articles have been published on the subject. Much of the literature reviewed tended

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[4]The model developed in Chapter III and Appendix A was first presented at the Conference on the Economics of Natural Hazards and their Mitigation, sponsored by the National Science Foundation at the University of Florida, December 14-15, 1984.

to rely on ad hoc theories which in some instances produced misleading and erroneous conclusions. It was this lack of an acceptable framework which forced the development of guidelines for measuring secondary losses. Only then could a critical evaluation of the literature proceed.

The Controversy over Losses

The controversy over what to count as a loss revolves around two issues. It has been argued that the summation of capital losses and regional employment effects involves double counting (Roberts et al., 1982). Since the value of capital is the discounted stream of income generated as the result of employing that capital, its destruction is tantamount to the destruction of the income stream. One might question whether the capital in question is the book value of a going concern or the replacement cost of plant and equipment. Other factors such as marketing, good will, customer allegiance, and like intangibles are involved in establishing a firm's value. What about human capital? No doubt some double counting exists, the question is how much and how can it be isolated.

A second reason for questioning the inclusion of employment effects in loss estimates is the claim that whatever one region loses another may gain. Hence, it is argued that from the standpoint of national economic efficiency such secondary losses might well be ignored. This contention is predicated on the assumption that excess capacity exists elsewhere and that the disaster-stricken region produces a generic product which could be manufactured elsewhere. In some instances these assumptions may be correct and in others they are not. Silicon Valley, for example, produces specialized equipment which may not easily be replicated. Bank computers located in downtown Los Angeles monitor transactions and process data for the entire western region of the country. It is doubtful that such services could be smoothly shifted to another banking center in the event of a catastrophic loss of computer facilities.

Problems with the First Attempts to Measure Secondary Losses

Early attempts to model the secondary effects of a disruption to a region's economy utilized Leontief transactions matrices (Cochrane, 1975). The technical coefficients embedded in the trade flows formed the basis of a linear program designed to maximize regional value added, subject to the postdisaster stock of capital. The obvious shortcoming of such an approach, pointed out by Roberts et al. (1982), among others, lies in the rigidity of these technical coefficients. The commodity flows on which the tables are built reflect the economy's long-run tendencies. That is, they represent the outcome of producers' decisions to employ the ingredients of production according to the industry's expansion path. For this method to work, the production function must exhibit constant returns to scale. It also should be noted that interindustry analysis is most useful when employed to forecast the effects of demand changes. Supply simply follows, while the labor-capital mix can be safely assumed to remain constant throughout the expansion. However, a supply shock offers an entirely different challenge. A sudden disruption to an economy's material and income flows can only be viewed as a surprise, triggering both producers and consumers to search for new and innovative short-run means of rebalancing budgets and production plans. Both groups would be forced to explore previously untried alternatives. This is the essence of the adjustment process. Since historical observations regarding catastrophic changes in production are rare, it is unlikely that input-output statistics would capture such effects. Because of this, Leontief models may be of limited value in analyzing catastrophes, especially if radical shifts in relative prices induce an alteration in spending and production plans are anticipated.

Roberts et al. also point out that input-output techniques would lead to conclusions which exaggerate the length and severity of the reconstruction process. "The recovery process is seen as the elimination of the input constraint, at which point the industry returns to its former level of activity, with the former product and input mix. This results in a severe overstatement of this aspect of economic consequences of an earthquake in a region. Furthermore, the assumption of constant product mix probably leads to overestimation of the length of the recovery period. It is reasonable that a catastrophic event would change the level of demand for many outputs and that many industries would respond to the changed demand by shifting the product mix to favor outputs which are useful in recovery" (p. 24).

An Ideal Model

The ideal measure of economic disruption according to Roberts et al. is "the change in value added with and without the event. . .The model should focus on the supply side constraints which are likely to arise in the event of a catastrophe, such as an earthquake. Much of the current economic modeling involves analysis based on the Keynesian model. The concern of these models is with the maintenance of an adequate level of aggregate demand and the assumption is that no supply side constraints are binding. . . .Supply constraints are likely to become paramount (in a catastrophe). Also from recent experience in the United States, insurance payments, capital inflows, and private and public philanthropy will combine to assure an adequate level of demand" (1982, pp. 21-22). Lastly, they point out that "the ideal economic model would incorporate all economic interdependencies. . ." (p. 23)

It is also important to note that value added is an indicator of economic activity, but is only indirectly tied to the victim's well-being. The magnitude of loss, in terms of willingness to pay to avoid the disaster's consequences, may far exceed any change in value added. Shifts in relative prices combined with altered patterns of production during reconstruction mask the effects on households. Value added is only a surrogate measure of welfare; more refined and focused indicators are needed. Such is offered in the following sections.

GENERAL EQUILIBRIUM MODELS: A TOOL FOR SORTING OUT THE ISSUES

From a theoretical standpoint, general equilibrium models (GEM) represent a vast improvement over interindustry techniques or linear programming. The inclusion of explicit production and demand functions permits a more refined assessment of how the economy is likely to respond to shocks. Prices can be tracked, substitutions observed, and welfare effects intuited. Employment of GEM to environmental issues is not new. D'Arge and Kneese pioneered such approaches in their analysis of pervasive environmental externalities. Whalley (1975 and 1977) applied Walrasian techniques to trace the effects of the 1973 United Kingdom Tax Reform. More recently, Kokoski and Smith (1984) utilized a technique similar to Whalley's to assess the effects of climate change in developed and developing economies.

The regional economic dislocations produced by natural disasters are not unrelated to the problems posed by environmental externalities or even sudden shifts in tax policy. They all begin with a shock to which the economy must adjust. The period of time required for achieving a state of normalcy is marked by altered trading patterns and relative price changes, which combine to affect social welfare. Cochrane (1985) demonstrated the use of GEM to assess the extent to which destruction of producer capital could cause income effects over and above losses traceable to direct damages. The approach is similar to that employed by Kokoski and Smith (1984) with two exceptions discussed below. The technique was refined for the purpose of this review and is presented in its entirety in Appendix A. A summary of the model's most important elements and the essential findings is presented.

The model is primarily intended to answer several questions important to dam safety risk analysis.

Are disaster-induced employment effects, the so-called secondary losses, simply another measure of damage to productive capital?

Why have empirical studies failed to detect these secondary effects?

Should government postdisaster recovery plans be directed toward the maximization of regional employment?

Will better dissemination of probability information lead to an optimum level of protection in the form of contingent claims either contracting or strengthening vulnerable structures?

It should be noted at the outset that in its current state the model is primarily pedagogical. It is a highly simplified representation of a regional economy embedded in a larger system. The producer and consumer equations and interindustry trade flows are designed to be realistic and flexible yet manageable.

A General Equilibrium Model of Disaster Response and Reconstruction

The size of the disaster GEM was purposely limited in order to highlight the postdisaster adjustments triggered by a sudden shortage of consumer and producer capital. Four producing sectors are represented, each of which combines labor and capital according to a different constant elasticity of substitution (CES) production function. Two of the four sectors produce consumer items; however, one of the two (best thought of as construction) also sells to other businesses and government. The remaining two sectors export items to other regions and produce an intermediate good utilized by the second consumer good industry (other than construction). The local government employs an income tax to generate revenues; its level of spending is exogenously given and is not tied to the occurrence of the disaster.

The economy's households are assumed to save a fixed proportion of their wage and interest income. The remainder is spent on the two consumer goods according to traditional utility maximizing rules; preferences are represented by a Stone-Geary function. The price of goods which could be imported from other regions prior to the disaster exceeds locally manufactured items. Hence, under normal conditions there are no imports. However, since imports are assumed to be an increasing function of local prices, they may be observed after the disaster.

For the sake of simplicity, the workers are assumed to be the owners of the economy's four industries. Hence, it is not necessary to distinguish profits and interest from wage income. Household consumption is a function of disposable income only. The wage rate is used as a numerare, against which all product prices are compared.

The capital available to the construction industry is assumed to be immobile and not readily expanded to meet postdisaster reconstruction needs. This assumption is essential in order to incorporate bottleneck costs into the rebuilding process; it will be demonstrated below that if capital were freely mobile, then secondary losses would be impossible. In actuality, reconstruction capital is neither as mobile nor immobile as suggested by these polar extremes. Within the damaged region, however, industries are free to lease capital (possibly buildings) to the highest bidder. In essence, the model permits the brokering of surviving plants and equipment.

The scenario employed in Appendix A focuses attention on secondary losses; the intermediate goods industry is assumed to be the only casualty of a collapsing dam. Both residences and the manufacturers of final goods are assumed to be spared. <u>The sum of both direct and indirect losses stemming from such a disaster is determined by computing the compensation that must be paid the victims in order to restore the region's predisaster level of welfare (i.e., utility)</u>. This point is extremely important, since it draws attention to a concept which is central to loss measurement. At the same time it is an idea which is easily misinterpreted. The compensation calculated is the minimum payment which must be transferred to the victims from outside the region in order to reestablish the region's level of welfare. The precise amount of aid required to accomplish this task hinges on the willingness of households to substitute more plentiful consumer items for those in short supply, the availability and price of imports, the ability of the affected industries to utilize relatively plentiful labor in place of scarce capital, and the willingness of the victims to remain in the disaster area. Their combined effects, in the context of a GEM, produce the correct measure of loss.

As just indicated there are a number of ways in which this approach can be misinterpreted. First, is it necessary to make the disaster payments? The answer is yes and no. This simulation is a thorough thought experiment, which traces both the impact of the disaster and the subsequent payments. If the disaster is large enough and significant bottleneck costs emerge from the resultant production constraints, then not only must compensation reflect this situation, the model must also account for the effects of the payments on the economy. A thought experiment could stop short of asking how the payment of disaster relief affects supply prices, but to do so could understate the amounts needed for full restoration. The thought experiment is complete once full compensation is determined. Whether this is ever paid is another question, quite unrelated to the problem at hand. The politics of disaster assistance should not be confused with the economics of loss measurement.

This point leads to a second issue which is equally confusing. That is, since the analysis is confined to a region, the losses may not be transferable to the nation as a whole The <u>Principles and Guidelines</u> (Water Resources Council, 1983) for conducting BCA permit the inclusion of flood control benefits which promote national economic development. Regional effects are, according to the P&G, of secondary importance. The question which must be addressed is whether these regional impacts are transferable. No doubt, under certain conditions the nation's economy would be affected, especially if the goods produced within the disaster area were of strategic value to the rest of the nation. What if this is not the case? Would a disaster in an economically isolated zone produce losses which are countable at the national level? The answer is yes providing certain conditions hold. Assume that the thought experiment outlined above is brought to its logical conclusion. Compensation of the amount X is required. This payment may prove to be small relative to the federal budget, but it must be accounted for in any event. In order to compensate the victims, the federal government would have to raise taxes, cut spending elsewhere, or borrow. Regardless of the instrument chosen, the effects are felt at the national level; there is no way to avoid it.

It might be asked once again whether compensation is actually paid. If it is not then why bother addressing fiscal impacts? The answer once again lies in the thought experiment. In order to fully understand the effects of the disaster one has to trace all of the effects. To stop short of this yields an incomplete picture of both the magnitude of the losses and the ultimate distribution of the burden. Seldom over the past two decades has the federal government failed to provide some form of disaster assistance in the wake of a truly large catastrophe. So even though it is possible that the victims of disaster would have to shoulder the burden alone, this has not historically been the case.

One might also argue that employment effects produced within the region would be lessened if labor simply migrated to where capital was more plentiful. By so doing the rate of unemployment would decline and secondary losses would be eliminated. In essence the argument is based on the assumption that workers and their families will move to any location which offers a wage approximating that received prior to the disaster. This of course ignores the fact that location is important to households, so much so that they would be (and have been observed to be) willing to sustain significant hardships in order to remain. Such hardships may be in the form of lower-paying jobs or lengthy periods of unemployment. Under such circumstances lost regional production is not made up elsewhere but simply reflects a lower living standard for residents of the stricken community. This is indeed a measure of loss which is borne by the region but can be legitimately considered a national loss as well.

Brief Summary of the Results

The effect of a hypothetical disaster was simulated utilizing the framework just described. A detailed explanation of the parameters and functions used are provided in Appendix A. The results can be succinctly summarized by the following observations:

> The compensation required to restore welfare can be less than, greater than, or equal to the value of the capital destroyed. It may take more than one time period for normalcy to return, in which case the cost of the disaster is the discounted stream of required compensation.
>
> If capital is perfectly mobile, disaster losses are identical to the value of capital destroyed. Damaged plant and equipment are instantaneously replaced at a cost equivalent to that prevailing prior to the disaster.
>
> If capital is not very mobile and imports are highly competitive (prices are equivalent) with regionally produced commodities, the damaged industry and other industries tied to it will never reopen. The losses in this case are the sum of direct damages, the cost of idle capital, and unemployed labor. In this instance

compensation payments would be used to purchase lower-priced imports. As a result the region's surviving capital stock would not earn rents (due to its scarcity), and there would be no reason to expand investment. The markets would be permanently lost.

If capital is immobile, imports are more expensive than regionally produced goods, and labor is easily substituted for the damaged capital, then the discounted stream of compensation is less than the value of capital destroyed. This results from the combined effects of spending multipliers and the induced investment accelerator.

Implications for Dam Safety Risk Analysis: Why Regional Effects Are of National Concern

These results are still preliminary although quite plausible; a more extensive discussion can be found in Appendix A. The implications of the findings for dam safety are severalfold. First, great care must be taken to sort out secondary from primary losses. Failure to do so could lead to double counting. In instances where strategic industries are incapacitated, secondary losses could be quite substantial and should be included in the list of consequences which a risk analysis entertains. For reasons pointed out above there is a legitimate rationale for including these secondary effects as part of a benefit-cost study of a dam rehabilitation program. In addition, multiobjective techniques should incorporate regional economic stability and recovery as one objective to be traded off against efficiency.

It is also clear, however, that not all disasters generate secondary losses. The event must be highly destructive, disrupting the economy's primary industrial base. Proximity to other industrial and commercial centers should lessen the disruptive effects. The empirical evidence regarding the effects of disasters on communities is varied, confusing, and at times ad hoc. This is due in part to the lack of a suitable framework for interpreting the statistics. The few studies which have been undertaken are reviewed below.

A CRITICAL REVIEW OF THE EMPIRICAL RESEARCH

Few studies have been conducted to measure disaster-induced economic dislocations. For a variety of reasons, the material that has been published tends to be contradictory and inconclusive. Despite this, however, a pattern has emerged which should prove of value in establishing simple guidelines for incorporating secondary effects into benefit-cost or risk assessment studies of dam safety. It is clear from the review, especially in the context of the framework developed above, that great care must be exercised in interpreting and extending published research to regions and disasters for which they were not originally intended.

During the early 1980s, the most often quoted and hotly debated evidence regarding the extent of secondary losses was produced by a group of sociologists at the University of Massachusetts, Amherst (Wright et al., 1979). Their research focused on the question: Does occurrence of a disaster alter the path of a community's economic growth, i.e, might the damages cause secondary effects which are detectable in secondary census data, specifically housing starts? Data were collected on approximately 10,000 events which occurred over the decade of 1960 to 1970. Simple regression analyses were performed to determine whether the so-called disaster-stricken communities suffered any lingering effects when compared with a randomly selected control group. The statistical analyses proved conclusively that no long-term impacts resulted. This highly provocative negative finding tended to be misread. It was relatively easy to wrongly conclude that the results showed no secondary impacts. Wright et al. were careful to point out that even though "We find no discernible effects of either floods, tornadoes, or hurricanes on changes in population or housing stocks experienced by counties in the period between 1960 and 1970" (p. 24), there are several reasons for this finding. "First, the damages and injuries directly attributable to the disasters are very small in relation to the population bases and housing stocks of the counties involved." "Second, disaster policies on the federal, state, and local levels in effect during the decade of the 1960s have been sufficient to provide enough additional support for reconstruction to dampen considerably the lasting effects of natural disaster events on counties."

The average tornado included in the Wright et al. study destroyed a mere three homes, hardly enough to tax even a small community, let alone a major metropolitan region. Adjustment costs should not be expected, and hence, many of the impacts highlighted above would be absent. There are several other reasons for discounting the relevance of these findings for the purposes of dam safety studies. Their conclusions are based on expected values, which is hardly an appropriate measure for a risk assessment. Second, it is a mistake to equate eventual recovery with the absence of secondary effects. Even the simple economy developed above, barring several special cases, recovers to its original state. The secondary losses are summed from the point when the disaster occurred to the time when recovery has been achieved. Last, the Amherst group argued that the provision of disaster assistance dampens the disaster's effects, thereby speeding recovery. This is probably true and is easily demonstrated with the simulation. However, isn't disaster aid a form of compensation, which in turn could both counteract and to some extent reflect the annual compensation required to restore welfare? Therefore, to some extent disaster aid includes the secondary effects Wright et al. were trying to measure. The aid itself could be a measure of secondary losses.

Has disruption been quantified and its significance determined as a result of <u>any</u> disaster? Cochrane (1976) attempted to assess the secondary effects of Cyclone Tracy which struck Darwin, Australia, in December of 1974, destroying every two homes in three. Darwin's remoteness on the north coast, nearly 2,000 miles from the nearest large city, made it an ideal candidate to isolate and measure indirect losses. The pattern of price changes tracked closely with that suggested by the simulation. Compared with the rest of Australia, construction costs in Darwin rose dramatically and remained above costs elsewhere for nearly a year and a half, before dropping back to the predisaster trend. A hedonic price index collected from real estate transactions (n = 211) in Darwin showed a pattern identical to that just described. Over the course of a year the sales price of the "average" house rose by nearly 25 percent before eventually declining.

Other studies of flood disasters attempting to detect similar dramatic shifts in price have produced negative results (Cochrane, 1979). The methods used in Darwin, when applied to Rapid City (1972), Wilkes-Barre (1972), Johnstown (1977), Harrisburg (1972), Elmira (1972), Corning (1972), New Orleans (1965), and Loveland (1976), did not detect any major break in the cost pattern. This could be explained in part by the disasters' magnitude. Each case represents a major event, but in proportion to the resources available within the region the task of rebuilding was not taxing. Ellson, Milliman, and Roberts (1983), in an attempt to measure secondary earthquake losses, reach a similar conclusion. They assert that damages are likely to be less than 10 percent, whereas the "historical variability of the ratio of gross annual investment to capital stock for the Charleston SMSA has been as high as 23 percent and is expected to average about 14 percent in the baseline projection. Annual variability of housing start ratios to housing stock often exceed 6 percent."

Despite the contradictory and predominately negative conclusions reported by disaster researchers, there is evidence that under extreme circumstances a break in the economic pattern can be observed. This was true in Darwin and was also detected in major snowstorms (Cochrane, 1982)[5] and major earthquakes, cyclones, and droughts (Cochrane, 1981).[6] It is clear from the literature reviewed that the extent of the disaster in proportion to the region's resource base is a key ingredient in shaping recovery and the economic dislocations which might be anticipated.

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[5] A statistical analysis of sales tax revenue as a function of snowfall showed that for extreme events, three times the monthly average, for example, retail sales drops by one fifth.

[6] A statistical analysis of the 75 worst disasters to occur world wide was conducted to determine their effects on economic growth. Cochrane, using earthquakes as an example, showed that direct losses in the amount of $20 per capita (approximately .05 to .20 percent of per capita wealth) would cause growth to drop from +5 percent to -6 percent.

SIMPLE GUIDELINES FOR CONDUCTING ANALYSES OF SECONDARY ECONOMIC LOSSES

The literature on disaster-induced secondary losses is confusing, area- and disaster-specific, and often misinterpreted. Few careful studies have been conducted. There is no tightly argued and accepted theoretical foundation for assessing impacts. As a result, barring a few exceptions, the empirical work is ad hoc and involves some degree of double counting. Based on these observations, it would appear to be unwise to launch costly data-gathering efforts for the purpose of refining secondary impacts without first formulating a practical and acceptable conceptual framework. A follow-up study or conference should be initiated to produce a simple set of guidelines for performing crude site-by-site assessments. Based on the literature reviewed and the conceptual framework developed above, such guidelines might appear as follows:

Illustrative Set of Guidelines for Including Secondary Economic Losses in Dam Safety Studies

Include secondary losses in the risk assessment if:

1. The anticipated direct loss is 25 percent or more of the community's stock of residential and commercial capital.

2. The structures and contents sustain severe damage (total loss).

3. The commercial losses are to primary industry (including agriculture) and manufacturing as opposed to retail and wholesale trade.

4. A unique economic activity not easily transferred elsewhere is at risk.

SUMMARY

Several questions were posed in the introductory section of this chapter. The questions are repeated and answers given based on what has been learned from the review.

Are disaster-induced employment effects, the so-called secondary losses, simply another measure of damage to productive capital? This is a special case which may be observed in a great number of "disasters," especially if the ratio of destruction to the resource base of the economy is low. However, the potential exists for employment effects to be quite large, particularly when a strategic industry is severely impacted.

Why have empirical studies failed to detect these secondary effects? A number of studies have focused on the longer-term prospects for recovery, which are somewhat different than income losses stemming from the disaster. Secondary effects are only observed for events which destroy a sizable percentage of the region's industrial base. Few, if any, of the disasters included in the statistical analyses reviewed were of this magnitude, hence, the conclusion "disasters do not impact long-term economic growth." Whether a catastrophic failure of a high-hazard dam could produce prolonged economic dislocations is still a matter of conjecture.

Should government postdisaster recovery plans be directed toward the maximization of regional employment? This is a laudable objective; however, it may not be consistent with regional welfare. Government policy should be designed to promote postdisaster recovery, which may (but not necessarily) be consistent with maximum employment. Recovery plans which focus on employment alone invite trouble by fostering production of commodities due simply to their high labor content. Such incentives could set the reconstruction process on a course which may take years to correct.

Will better dissemination of probability information lead to an optimum level of protection, either in the form of contingent claims contracting or strengthening of vulnerable structures? When it comes to secondary losses, it is not clear that decision makers, either private or public, can anticipate the extent to which the economy is vulnerable. Hence, it is highly unlikely that the level of protection afforded to sensitive economic sectors is satisfactory.

IV. PSYCHOLOGICAL IMPACTS OF DISASTER

INTRODUCTION

The primary purpose of this chapter is to discuss the present state of knowledge regarding disasters and their relationships to the mental health of impacted populations. As part of the discussion a brief summary of the literature on disasters and their mental health consequences is offered and critiqued. Then, a series of postulates derived from the literature on disasters and psychological stress are combined to form a comprehensive set of guidelines for those interested in determining the relationships between dam failure disasters and mental health.

DISASTERS AND TYPES OF PSYCHOLOGICAL IMPACTS

Disasters, such as those produced as a result of dam failures, have the potential to significantly disrupt ongoing social and community systems. Disasters, therefore, are significantly different from individual life crisis events, such as untimely death, since they tear the social fabric on which individuals depend (Fritz and Marks, 1954; Fritz, 1961; Barton, 1970; Quarantelli and Dynes, 1973). It is almost self-evident that disasters impact social systems as well as individuals. However, the nature of the sociological and psychological impacts is more complex than one might initially believe. Contrary to first impressions which focus on the negative, postdisaster impacts can have a positive effect on the community as well.

Positive impacts of disasters (Janis, 1951; Fritz and Marks, 1954; Fritz, 1961; Wilson, 1962; Coleman, 1966; Barton, 1970; Quarantelli and Dynes, 1973; Quarantelli, 1979) are largely social-psychological and define how a disaster event serves to precipitate a strong sense of identification among members of the affected community. This identity functions to elicit a therapeutic collective response to disaster problems as victims aid victims and engage in other helping behavior to service disaster-induced community needs. This positive impact is temporary, and although it serves to explain short-lived community disaster response when immediate disaster needs are high, it does not preclude psychological impacts.

Disaster-induced psychological impacts are of two sorts. The first is short-term and results from social disruption and a sense of loss; this is identified as psychological distress. The second is long-term psychological impacts such as psychic traumas, psychological or psychiatric disorders, gross psychopathologies, and mental illness. Research on the psychological impacts of disasters has documented widespread short-term distress among disaster populations, a subset of whom then develop long-term impacts (Tyhurst, 1957; Menninger, 1952; Rosenman, 1956; Wallace, 1956; Wolfenstein, 1957; Glass, 1959; Crawshaw, 1963; Farber, 1967; Lifton, 1967; Krystal, 1968; Kliman, 1973; Schulberg, 1974; Erikson, 1976; Lifton and Olson, 1976; Newman, 1976; Rengell, 1976; Stretton, 1976; Titchener and Kapp, 1976; Raphael, 1977; Gleser, Green, and Winget, 1981; Houts et al., 1980; Baum et al., 1981; Kasl et al., 1981). Other research also points to the occurrence of short-term distress but suggests that the disasters investigated elicited few cases of long-term psychological or psychiatric impacts (Janis, 1951; Fritz and Marks, 1954; Marks et al., 1954; Form and Nosow, 1958; Ikle, 1958; Bates et al., 1963; Moore et al., 1963; Drabek and Stephenson, 1971; Drabek et al., 1973; Zusman et al., 1973; Hall and Landreth, 1975; Peipert, 1975; Dohrenwend et al., 1979, 1981; Bromet, 1980; Bromet et al., 1982; Bromet and Dunn, 1981). Finally, some research (Finichel, 1958; Kardiner, 1959; and others) suggests that long-term impacts are likely to be problematic for those individuals who have a history of psychological vulnerability or psychiatric illness. Consequently, the current state of knowledge regarding the psychological impacts of disasters, such as dam failures, suggests that short-term distress is a cost borne by disaster populations, while long-term impacts and illness can also occur. But the latter impact can only occur in instances where the individual is psychologically vulnerable. This group comprises a very small segment of the population.

PSYCHOLOGICAL IMPACTS AND HEALTH

Short-term disaster-induced stress and longer-term psychological and psychiatric illnesses are not the end point in tracing psychologically related disaster impacts. Stress, for example, is increasingly thought to be a precursor to physiological illness. Such has been noted by Rahe and Arthur (1978) in their analysis of physiological illness observed in the late part of the last century. Holmes and Rahe (1967) have documented that stress is a determinant of physiological illness which proceeds in the following manner: (1) situation, such as disaster, (2) perception, (3) psychological defenses, (4) psychophysiological response such as stress, (5) response management, and (6) physiological illness (Rahe and Arthur, 1978, p. 7). Presumably, stress adjustment requires physiological changes which predispose persons to illness. Thus, there is a chain of causes and effects between stress-inducing events like disaster and resultant physiological illness. Rahe and his colleagues maintain that any changes are stressful, even desirable ones such as promotions at work. Subsequent research has shown, however, that "undesirable" events such as a disaster are far more influential in producing illness and psychiatric symptoms (Ross and Mirowsky, 1979).

More recent research has refined these observations. New variables have been added to explain the linkage between stress and illness. One variable was mentioned above, that is, whether the event is a desirable or an undesirable one. A second variable relates to whether the subject has control over the life events under consideration. For example, subjects presumably would have very little control over events such as the death of a spouse or a disaster produced as a result of dam failure, but might have considerable control over divorce, marital separation, or voluntary surgery. It is now thought that events that can be controlled produce less stress than those that cannot. The degree to which subjects expect an event to occur and the amount of adjustment an individual is required to make in response to the event have also been considered relevant dimensions of stress (Isherwood et al., 1982a,b). The notion here is that unexpected events, such as a death in the family, require a substantial degree of readjustment.

Regardless of the model or theory used, all researchers agree that there are a number of intermediate steps separating the triggering event and the development of some kind of stress-related behavior and illness. These variables include those which have a psychological orientation, such as the adequacy of a person's coping defenses; social variables, such as the presence or absence of a support group; and physiological variables, such as the quality of the individual's body chemistry. The potential for one or more of these factors to play a role has complicated the prediction of resultant behavior. Kosaba (1979) pointed out that correlations between stress and illness can range from .20 to .78 and that the majority are under .30 for the early research projects. The resulting illnesses which can surface as a consequence of stressful events such as disasters include myocardial infarction (Connolly, 1976; Theorell and Rahe, 1975; Rahe and Romo, 1974; and others) or heart attack; automobile accidents (Farberow, 1980; Selzer and Vinohur, 1974; McMurry, 1970; and others); suicide (Isherwood et al., 1982a,b; Paykel, 1976; Paykel et al., 1975; Birtchnell, 1970; Henry and Short, 1954); and ulcers (Susser, 1967; Wolf, 1949), to name but a few.

IMPACTS AND THEIR INDICATORS

The array of psychological impacts associated with disaster include short-term impacts (distress), long-term impacts (psychic traumas, disorders, psychopathologies, and mental illness), and health effects (heart attack, ulcers, and so on). These impacts are interrelated, for example, health effects stem from distress. Distress is potentially greatest in disasters which contain many of the aspects associated with dam failure, and long-term and health affects are likely to manifest themselves only in a small subset of the total disaster population.

A variety of devices exists through which psychological short-term, long-term, and health affects of disasters can be measured. Questionnaires and standardized batteries of questions (Bromet, 1980; Houts et al., 1980; Bromet and Dunn, 1981) exist that can be used in an interview format in which subjects report symptoms and answers to nonsymptomatic questions that collectively can be used to measure stress and illness. This approach is useful but is also subject to respondent bias. A second approach is through the use of existing data sources and records, such as health records regarding the incidence of heart attacks, suicide attempts, and so on (Mileti et al., 1984). A third approach, albeit an impractical one, is physiological (Baum et al., 1981) and uses direct biological measures on individuals, such as measuring the secretion of glandular fluids, known to occur with distress, in blood and urine. Finally, psychiatric and psychological assessments can be performed on individuals to catalog case data on the individuals under examination.

The prevalence of psychological impacts associated with disaster varies and is a consequence of specific disaster aspects. Warheit (1985) has attempted to catalog aspects of the disaster which are relevant. These include the suddenness of impact, the degree to which the impact can be avoided, and others, as well as aspects of the people being affected, including sources of social support, disaster experience, predisaster psychological vulnerability, level of resources available to cope with the disaster, and others. Based on the accumulated record, it is the authors' impression that distress is common to at least half of the population affected by disaster and that long-term and health effects would occur in about 1 percent of the population.

V. FLOOD WARNING SYSTEMS: POTENTIAL FOR REDUCING LOSS OF LIFE

CONCEPTUAL FRAMEWORK FOR ASSESSING WARNING EFFECTIVENESS

Warnings of High-Probability, Low-Consequence Events

The economics of weather information is a highly developed field, boasting almost three decades of research producing upward of 500 publications. The earliest studies, Thompson and Brier (1955), Lave (1963), and Nelson and Winter (1964), focused primarily on repetitive events, such as precipitation and frost. These models were designed to optimize the net benefits of employing forecasts. In its simplest form, the method contrasted the expected losses anticipated as a result of weather events (without the receipt of a forecast) with the costs of employing preventative measures (triggered by the receipt of a forecast). The value of a warning in this context is the net gain to the user. That is, if the warning reduces losses by X dollars and the cost of undertaking protection is Y dollars then the warning must be worth X minus Y. It is important to note that both X and Y are expected values and, therefore, include instances where protection was adopted and not needed. Conversely, it also includes instances where warnings were not issued and losses were sustained. Despite their simplicity, these models produced several critical contributions. The most important is that they put warning studies on an unambiguous footing. Improvements could be measured in terms of a reduction in the value of type I and type II errors. As a corollary, these studies pointed out that warnings are not inherently valuable; they may cost more to implement than they save. They also resolved confusion regarding the losses. Total damages were shown to be a poor guide for prioritizing potential improvements to warning systems. The key to evaluation proved to be <u>the loss which could be avoided</u>.[7] Last, they underscored the conclusion that the accuracy of a forecast is not a direct measure of its value. The object of the Weather Service should not be one of maximum accuracy. Under certain circumstances enhanced accuracy may be of no value to the user, since the cost to implement could exceed the losses avoided.

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[7]To illustrate, the value of a hail forecast to a midwestern wheat farmer is nil; there are no feasible options for acting on such information.

In spite of the role these models played in clarifying forecast value, they proved to be inappropriate for flood-hazard analysis. The following assumptions are particularly questionable:

Adjustments (i.e., protective measures) to a weather event were conceived to be discrete, that is, their implementation carried a fixed cost; once adopted they were perfectly effective.

Protective action was triggered by the forecast and psychological and social aspects of warnings were ignored.

The forecast was dichotomous, i.e., frost, no frost or rain, no rain.

Losses were fixed at some positive amount if the event occurred, but were assumed to be zero otherwise.

The interaction of adjustments (e.g., warnings and structural measures) was ignored.

Costs and losses were depicted in comparable units (dollars).

Several of these problems have been subsequently rectified. Dichotomous events gave way to a continuum (Howe and Cochrane, 1976); inches of rain replaced the events rain and no rain. The interaction of a wider set of protective measures was introduced to show that warnings could only be evaluated in the context of other options (Howe and Cochrane, 1976). Weather forecasts, and the short-run protective measures they might spawn, must compete for the same pool of benefits that levees, land use, and flood control reservoirs were designed to produce. This optimization over a broader set of hazard adjustments focused attention on the interactive effects of alternative measures to cope with weather-related losses. It demonstrated the inefficiency of a strategy resulting from an analyses of warnings independent of other options.

A number of refinements have been introduced since 1976. Cochrane (1982) demonstrated that the combination of categorical and probability forecasts improved the value of warnings.[8] Katz, Murphy and Winkler (1982) showed that the expected loss at any time is contingent upon the losses previously sustained. For example, a frost which destroys a fruit crop renders future frost forecasts valueless. The same applies to flooding; flood forecasts which occur after a catastrophic event are

[8]Categorical forecasts refer to the amount of precipitation, etc., that is expected to occur. Probability forecasts indicate the probability an event will occur. Cochrane (1981) used both the magnitude and the degree of belief the forecaster had in his/her prediction. For example, the expected amount of rain is one-half inch; the standard deviation is one-half inch.

worth less since the number of structures at risk have been reduced. More recently Ferrel and Krzysztofowicz (1983) and Krzysztofowicz and Davis (1983) combined the approaches developed above with a behavioral model[9] of warning response to establish a mechanism for evaluating system effectiveness.

Applicability to High-Consequence, Low-Probability Events

Despite the progress which has been made over the past three decades of model building, it is questionable that the approaches developed are readily transferable to high-consequence, low-probability events. First, the consequences considered above are normally limited to property losses, economic disruption, lost income, or simple inconvenience. The utility of these models diminishes once the potential for significant loss of life is introduced. With the exception of "cost-effectiveness," the optimization models cited above require that both costs and benefits be evaluated in the same units, i.e., dollars. In order to do so, nonpecuniary effects must be reduced to monetary units. (See the section on valuing life for a discussion and criticism of alternative methods which have been proposed.) Aside from the problems mentioned, a National Research Council (1983) study of dam safety criteria has strongly recommended against the practice of placing a value on a human life in order to evaluate the merits of enhancing dam safety. "The Committee felt that a dollar amount should not be assigned to the value of a human life" (Duncan, 1985).

Without exception, these normative models employ overly simplistic assumptions about the processes involved in disseminating and acting on a warning. It is not uncommon for model builders to ignore these considerations altogether, thereby tacitly assuming a stimulus-response mode of behavior. Whether the population at risk hears the message, understands it, or knows what to do is of no consequence. If pushed, such analysts might argue that any observed failure to take precaution implies that the benefits must not have exceeded the costs or that the individuals possessed some strange preference for risk. Even the formal model of learning suggested by Ferrel and Krzysztofowicz (1983) is founded on the assumption that people learn from flood events. Whether this is true or not is moot when the probability of failure is low (e.g., .0001).

It is clear that an important, if not the primary, reason for improving dam safety is protection of life. Forecasting the number of people that might be saved in the event of a dam failure turns on a set

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[9]The response model is primarily Bayesian which includes four interconnected cognitive elements: (1) uncertainty about flooding prior to the flood, (2) sequential inference during the flood, (3) response strategy, and (4) learning after a flood (Ferrel and Krzysztofowicz, 1983).

of factors which bridges a number of disciplines. As will be illustrated in the following section, forecasts which ignore organizational, attitudinal, and information processing issues should be viewed with some skepticism.

WARNINGS VIEWED FROM A SOCIOLOGICAL PERSPECTIVE[10]

Warning systems designed to reduce loss of life are not as easily implemented as assumed in the rational model formulated above. Organizations are not as efficient, sensitive, or well informed of alternative courses of action or the extent of the risks posed by a catastrophic dam break. Populations that are warned often ignore the message, believing that it was intended for someone else, don't understand the implications, or are simply reluctant to evacuate. In many instances it is received too late to be of any value. Given the numerous points in the communications network where the system could break down, it is surprising that hazard warnings are at all effective, but in most instances they are. Much has been learned over the past 20 years of research as to why systems fail. Lessons have been garnered from investigations of tornadoes, flash floods, hurricanes, landslides, and toxic chemical spills. It is our opinion that dam failures are sufficiently similar so that the findings from these other hazards could be safely extrapolated to improving the effectiveness of warnings triggered by a collapsing dam.

Organizational Problems

Warning systems are typically characterized in the literature as a network of interconnected organizations tied together by a series of communications links and decision points (McLuckie, 1970; Mileti, 1975; Perry and Mushkatel, 1984; Mileti, Sorensen, and Bogard, 1985; Mileti and Sorensen, 1986). (See Figure 5.) The particular agencies and/or organizations involved will of course vary from hazard to hazard, but the nature of the warning process is generalized as shown. The key to understanding why organizations fail to properly discharge their responsibilities can in almost every instance be traced to an uncertainty and ambiguity in one or more of these decision points and communications links.

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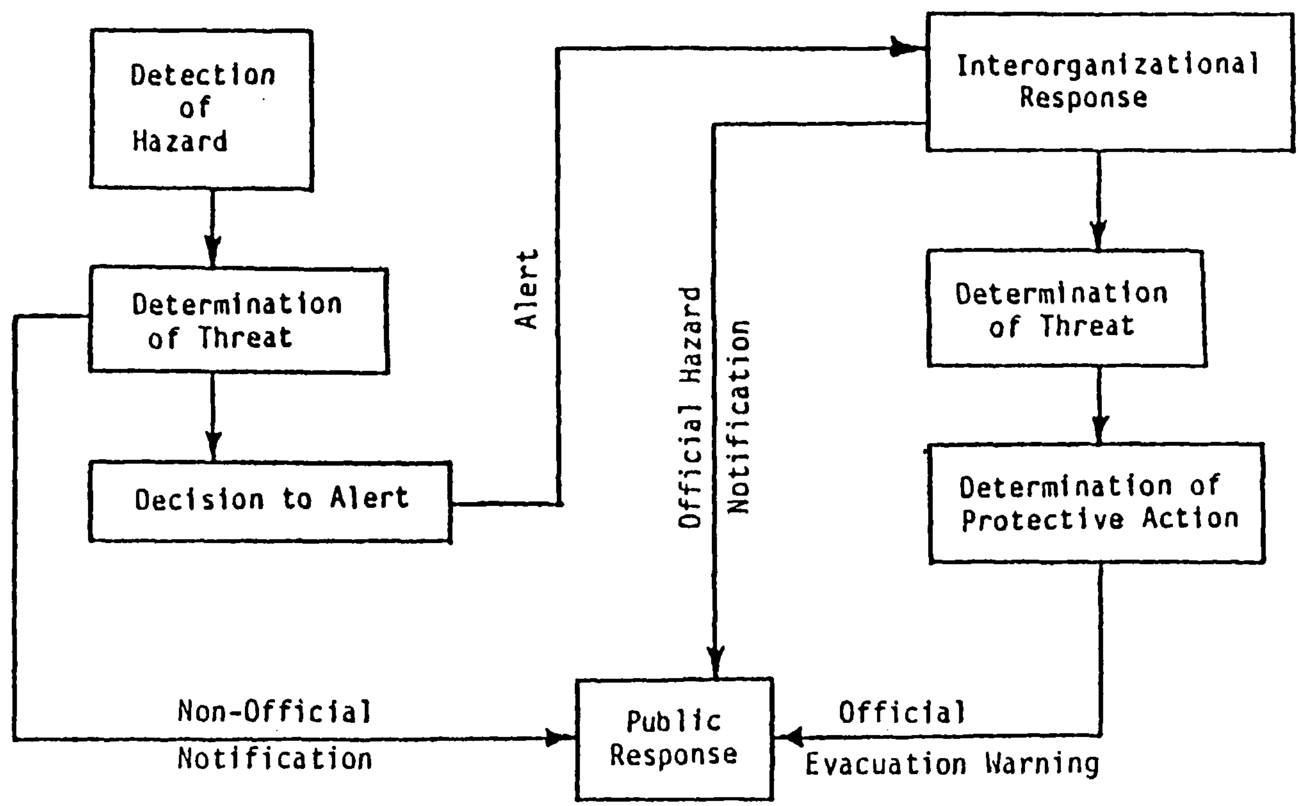
[10]A comprehensive review of empirical studies of warning systems revealed that there are 55 studies across hazard types which address organizational aspects, and over two dozen scientific publications focusing on public response. Copies of all organizational and public response studies are owned by Dennis Mileti and maintained in a computer-based retrieval system in the Hazards Assessment Laboratory at Colorado State University. This review is in part a condensation of the work performed for FEMA Oak Ridge National Laboratories.

FIGURE 5

WARNING SYSTEM DECISION PROCESSES



Source: Mileti and Sorensen, 1986.

Key Decision Points

The obvious starting point for a warning system is detecting the presence of a hazard, for example, an extraordinary rate of rainfall, a sudden rise in a river gage, seepage around a dam, etc. In most instances monitoring and detection are the responsibility of public agencies, but this does not preclude the involvement of private individuals. Once detected, the risks to life, health, and property are evaluated to determine whether the threat is sufficient to warrant subsequent action.

Once a threat is judged to be significant, a decision is made regarding how and when to alert those determined to be at risk. For some hazards well-developed plans leave little discretion, while for others the process is more *ad hoc*.

Key Communications Links

Once a hazard has been detected, information is normally passed on to an agency with emergency powers and responsibilities. Such information may also be disseminated to the public, either before, after, or at the same time local officials are notified. Finally, agencies responsible for carrying out an evacuation are charged with supplying the public with details regarding routes, who should leave, and how.

Organizational Uncertainties

The creation of an effective warning system is tied to the reduction of uncertainty surrounding each of these decision points and communications links. A topology of these uncertainties drawn from the literature is presented in Table 4 (Mileti and Sorensen, 1986).

Interpretation

The risk dam failures pose to life and health is directly linked to a complex of factors each of which could play a contributing role. Studies of disasters have shown that recognizing the severity of the event is highly variable (Mileti, Sorensen, and Bogard, 1985) and is partly the reason for the observed failure to warn when such an action was clearly warranted. For example, it was discovered that in several recent dam failures the private company responsible for managing the reservoir did not understand the relatively high chances of a collapse. Furthermore, after a prolonged period of heavy rainfall, when failure was imminent, the companies apparently overlooked the potential linkage between runoff and a dam break. Both the Buffalo Creek and Lawn Lake dam failures were characterized by such a sequence of events. In both cases faulty interpretation led to delayed warnings and subsequent loss of life.

TABLE 4

ORGANIZATIONAL WARNING SYSTEM UNCERTAINTIES

Interpretation

Recognition of event
Recognition of consequences/likelihood
Definition of magnitude
Self-definition of role
Recognition of relevant information
Definition of authority

Communications

Who to notify
Ability to describe hazard
Physical ability to communicate
Conflicting information

Perceived Impacts of Decision

Causing panic, looting, or other adverse responses
Loss of job/other personal consequences
Cost of evacuation or economic loss
Liability

Exogenous Factors

Time availability
Feasibility of evacuation
Prior experience
Planning
Outside pressures/expectations

Source: Mileti and Sorensen, 1986.

Uncertainty regarding the level of threat is a second, but no less important, reason for improperly interpreting risks. Under- or over-estimating the geographical extent and depth of inundation, for example, is without question one of the most prominent reasons why evacuations are poorly timed and ill executed. Examples of this are numerous. The Rapid City flood (1972) serves as a vivid illustration (Mileti and Beck, 1975; Mileti, 1975). Heavy rains and rising water were both detected; however, no one anticipated the extent to which the failure of a dam created from flood debris would alter the inundation area and the velocity of the floodwaters (Mileti, 1975). In another instance, a hazardous material spill resulting from a train derailment outside of Mississauga, Canada, resulted in the evacuation of 225,000 people. Although serious injuries were reported to be minimal, the risks of a serious problem increased significantly when the evacuation was delayed until authorities resolved uncertainty regarding the nature of the spill (Burton, 1981).

Even if the event is detected and the magnitude correctly forecast, the decision maker may fail to execute an evacuation if roles and obligations are misunderstood. Using Buffalo Creek to illustrate (Erikson, 1976a), the mining company responsible for creating the slag heap reservoir did not define their role as one which included the issuance of a warning. Failure to assume this role left a gap in the warning system, which produced one of the worst dam disasters ever recorded in the United States.

The volume and complexity of the information which the warning agency must process could lead to similar results. Sorting out what is relevant takes time, thereby reducing the lead time available to execute an evacuation. A hypothetical nuclear emergency is used to illustrate this point. A sheriff who is charged with the responsibility of deciding whether to activate an evacuation alarm system in the vicinity of a power plant might receive recommendations from three different organizations about such disparate and unfamiliar subjects as plant condition, meteorological factors, projected dose rates, etc. Confusion is the most likely result of information overload. At the extreme, the warning agency may be so overwhelmed they forget that their primary task is the issuance of a warning. This is in fact what happened during the Mount St. Helen's eruption. Emergency response organizations were given "raw" data on seismicity and plume activity. In the course of trying to understand these data, they neglected their primary responsibility, to warn the public (Sorensen, 1981).

Warnings may be delayed in the event more than one organization assumes it is primarily responsible for the safety of the population at risk. Interagency conflict occurred just preceding the Mount St. Helen's eruption (Sorensen, 1981). Disagreement over evacuation authority arose between the U.S. Forest Service and a lumbering company. A conflict over whether to evacuate areas where timbering operations were underway led to a series of revisions and compromises on both sides. Fortunately, the eruption occurred on a Sunday when logging activities were idle. Otherwise this conflict could have produced a catastrophe of greater proportions (Sorensen, 1981). Similar results have resulted in situations where no agency takes the lead, thinking instead that the responsibility rightfully belongs to another.

Communications

Most warning systems are a product of a long chain of messages, any break in which has been shown to delay or altogether preclude the execution of an evacuation (Mileti, Drabek, and Haas, 1975). Knowing whom to notify, how to describe the hazard, the availability of communications equipment, and the ability to minimize conflicting information are all important elements.

Technical jargon is one large obstacle which has time and again impeded communications among emergency agencies and between agencies and the public. Probabilistic information has proven to be particularly problematic (Mileti, Hutton, and Sorensen, 1981; Kunreuther et al., 1978; Perry and Mushkatel, 1984). The inability of some scientists and technicians to describe a hazard clearly and concisely has at times caused confusion and delayed action. A chemical explosion, occurring in Taft, Louisiana, for example, was described by company officials in such a way that local authorities could not react (Quarantelli, 1983).

Technical limitations and constraints have been responsible for delaying the issuance of effective warnings in numerous instances. Equipment which utilizes different radio frequencies, the lack of dedicated phone lines when regular lines are overloaded, and a shortage of backup systems are all too common occurrences. The loss of a phone system in the Johnstown flood (1977) hampered efforts of both the Corps of Engineers weather observer to determine rainfall amounts and the National Weather Service (NWS) to alert local authorities (National Weather Service, 1978).

It is equally important to note the effects of conflicting information. Savage et al. (1984) rationalize that warning to evacuate parts of Galveston, Texas (Hurricane Alicia, 1983) was postponed due to such a conflict--local officials relying on forecast information from both the National Hurricane Center (HRC) and the Galveston National Weather Service Office. The messages from the two organizations were significantly different, HRC indicating a more southerly landfall, while the Weather Service office forecasted a course with Galveston in its path. The local officials relying more heavily on the HRC prediction were unprepared when the storm veered north, at which point it was too late to evacuate.

Perceived Consequences of Making a Mistake

The decision to order an evacuation turns in part on a decision maker's perceptions regarding the adverse consequences such an order could produce. Concerns such as safety of the evacuees and their property have on more than one occasion given local authorities cause for concern. While the prospects of looting have been shown to be exaggerated, the image continues to persist (Mileti, Sorensen, and Bogard, 1985). This, along with the fear that false warnings (the so-called cry wolf syndrome) would detract from the effectiveness of subsequent attempts to evacuate, has served as an impediment to achieving warning system efficiency. It was reported that fear of panic was a key factor in the state government's failure to issue a general evacuation order for those caught in Hurricane Carla's path (Ruch and Christenson, 1981). Fear of alarming people falsely has been documented in studies of Hurricane Alicia for which warnings were not issued. It appears that local governments had previously conducted an evacuation as a result of the threat posed by Hurricane Allen. It is thought that the fact that Allen failed to materialize gave local authorities cause for concern about being wrong a second time. As a result no warning was issued for Alicia (Ruch and Christenson, 1981).

In the highly charged environment which typically accompanies the threat of disaster, uncertainty can lead to apprehension about communicating with the public and other agencies. Often this produces a situation in which the threat is downplayed. In essence officials responsible for issuing warnings simply do not wish to appear foolish and thereby lose their reputations (and possibly their public office). Evidence of this phenomena was detected by Anderson (1970) in a study of the 1964 Crescent City tsunami threat.

There is also evidence to suggest that these same officials can be influenced by the perceived <u>costs and losses</u> incurred as a result of ordering an evacuation. In some instances the expense of transporting and sheltering evacuees, combined with the costs borne for emergency personnel and lost sales, production, and employment may be viewed as placing an intolerable burden on local resources. Implausible as this may at first seem, several of these factors did shape the evacuation of Mount St. Helens. Perceived economic losses played a significant role in determining evacuation zones, where boundaries were shifted in order for two counties to split the costs of manning roadblocks, and to allow access to economic enterprises in the area (Sorensen, 1981).

How individuals and agencies perceive their <u>liability</u> has been shown to play an increasingly important role in influencing the dissemination of warnings. There are several reasons for this. First, liability for public safety is a concern which is frequently raised within public agencies. The possibility of being held responsible for damages if a disaster occurs and actions are not taken to protect the public is a preoccupying consideration. This perception tends to cause officials to err on the side of caution. In some instances, however, decision makers may perceive that they would be liable for damages incurred as a result of ordering an action which, in light of events, proved to be unnecessary (Mileti and Sorensen, 1986). The extent to which this consideration has actually altered the behavior of emergency agencies has yet to be carefully measured. Therefore, the extent of its influence on warning systems is still a matter of conjecture.

Exogenous Factors

A number of other factors, which defy a tidy classification, have been discovered to influence warning effectiveness. They are lumped under the title "Exogenous Factors" for lack of a better term, since they are not inherent to the warning system itself (Mileti and Sorensen, 1986).

The time available to implement an emergency plan, once a threat has been detected, influences both the efficiency and the effectiveness of protective measures. Concern over adequate lead time to conduct an evacuation, for example, may lead to decisions to evacuate before sufficient information about the hazard has been collected and assimilated. An example is a decision to evacuate a beach community or barrier island before the path or magnitude of a hurricane is known. Such was the case in 1980 when Hurricane Allen threatened the Texas shore communities. The decision to evacuate had to be made at a point when the storm's path was still highly uncertain (Ruch and Christenson, 1981). As a result, the NWS advised the evacuation of Galveston, only to have the storm veer to the south (Mileti and Sorensen, 1986).

Evacuation feasibility refers to the perceived degree of protection an evacuation would provide the public. Feasibility can be influenced by factors such as the severity of the hazard, geography, and safety of evacuation routes. Misperceptions could lead to ill-conceived evacuations. For example, the fear of a radioactive release during a fast-moving accident at a nuclear plant, in conjunction with poor weather, could lead to an evacuation decision prior to development of plant conditions that would normally trigger such an action.

Prior experience with public warnings, evacuations, and emergencies can influence a decision maker's judgment. It is not uncommon for emergency personnel to imagine that a new threat will have characteristics similar to those which have already been previously experienced, even though this image may be inconsistent with current information about the impending event. On the other hand, lack of experience with a particular hazard can, for some, produce uncertainty. Experience, and the uncertainties it can raise, can lead to either premature or tardy communications and evacuations (Mileti and Sorensen, 1986). This situation was experienced at Crescent City, California, in 1964. The warning of a potential tsunami which proved to be a false alarm played a role in delaying law enforcement officers' decisions to evacuate people given a subsequent threat (Anderson, 1970).

The presence, absence, or extent of in-place evacuation plans can greatly influence evacuation decisions. Experience shows that the lack of a plan can delay or confuse decisions to evacuate. Theoretically, possession of an evacuation plan could increase the likelihood of having an evacuation merely because it has been planned for. Additionally, emergency plans which are too rigid and too inflexible can themselves frustrate timely emergency response (Mileti and Sorensen, 1986). The accident at Three Mile Island (TMI) provides an example of the former (President's Commission on Three Mile Island, 1979). The lack of a plan definitely contributed to confusion over evacuation decisions. Likewise, the absence of plans for special facilities like hospitals in the vicinity of TMI may have contributed to decisions to allow hospital employees to evacuate without considering the consequences (Maxwell, 1982).

Evacuations can be influenced by the expectations or demands of persons outside the target area. For example, a public official may perceive that the public expects an evacuation. In addition, a decision maker may feel pressure from another level of government or some other agency when deciding whether or not to conduct an evacuation. At times the pressure may be counterproductive when the responsible official overacts to the pressures and follows the opposite course of action (Mileti and Sorensen, 1986). At TMI, the governor's decision to recommend a selective evacuation was, in part, a response to outside demands and pressures to demonstrate control and leadership (President's Commission on Three Mile Island, 1979). During the approach of Hurricane Alicia, communication from the governor to the mayor of Galveston regarding evacuation may have played a role in the decision not to evacuate. In this case the mayor may have reacted negatively to the state's position (Savage et al., 1984).

Factors Shaping Public Response to Warnings

The Process in General

It is clear from the literature (Mileti and Sorensen, 1986) that a stimulus-response model of public reaction is overly simplistic. A more complex process appears to be involved, one which embodies the following six steps: (1) hear the warning, (2) understand it, (3) believe it, (4) personalize it, (5) decide to act, and (6) respond. Many of the rational models discussed above overlook the stages between (1) and (6), inadvertently assuming instead that the issuance of a warning is synonymous with hearing and responding.

A warning system can fail to achieve the desired response if any one or more of these steps is violated. It is highly unlikely, for example, that warning of a dam failure issued over an emergency broadcast system would be heard by all in the target area, even if repeated. Some may simply not be listening or they may only hear what they wish to believe (selective perception).

If the message is heard, it may not be understood (Perry, 1979), that is, its meaning may be unclear. For example, a flood warning may be understood to mean a life-threatening wall of water to some but could be interpreted as merely inconvenient runoff to others. A probability of 50 percent may be viewed as certainty to some and "unlikely" by others. In each case individuals are asked to attach meaning to the message. The outcome is therefore highly dependent on perceptions of risk, which are grounded by personal frames of reference.

Once a warning is understood, a degree of belief (Drabek, 1969) is attached. Believability is influenced by the contents of the message, its consistency, and the context (Perry, 1979). Provided that the message is convincing, people have been shown to consider its implications for themselves and those for whom they feel responsible (usually their family). If the warning is thought to be targeted for another group, it will be ignored. Thus, personalization (Mileti, 1984) can lead to either over- or underreaction, depending on how the decision maker sees the threat. Even after hearing, understanding, believing, and establishing that the warning is directed to them, appropriate response could still be thwarted. This would occur if the sender supplies insufficient information about courses of action.

Sender: Factors Which Promote Successful Protective Measures

Ten factors have been repeatedly reported in the literature as influencing the public's acceptance of a warning (Mileti and Sorensen, 1986). The first is the source of the information; it must appear to be reliable and credible (Mileti et al., 1981). Since these are highly subjective qualities, it is not surprising that single source warnings would result in a lesser degree of compliance than one which is endorsed by a broader mix of engineers, scientists, and local officials. Second, message consistency about degree of risk appears to be essential (Drabek and Stephenson, 1971). Third, a warning should contain information which is timely, accurate, and complete. It has been learned that if people believe they are not receiving the "whole story," they are likely to pay less attention to instructions and, instead, act on the basis of their suspicions (Mileti and Sorensen, 1986).

Fourth is the clarity of the message (Mileti et al., 1981). Complex warnings utilizing scientific jargon have been shown to go unheeded. Fifth, a warning conveying a sense of certainty about the event taking place tends to boost the recipient's degree of belief and enhances the prospects of evacuation (Mileti et al., 1981). Sixth, the message should carry sufficient information. Research has shown that people tend to fill gaps in their knowledge with perceptions which may distort the true picture. The information provided through official channels serves to promote understanding, personalization, and decision making (Drabek, 1969). Seventh, a message should contain a clear statement guiding those in danger to take appropriate action. Eighth, a warning should be repeated at predictable intervals. This may appear self-evident, but if done properly this tactic can reduce anxiety, dampen the spread of rumors, and stimulate a response appropriate to the level of threat. Numerous studies underscore the importance of repetition as a precondition for response (Mileti and Beck, 1975). Ninth is locational specificity. A warning should clearly state the areas which could be affected. Belief and personalization are both enhanced by this important aspect. Last, multiple channels appear to be more effective than a single channel in promoting response (Mileti, 1984).

Receiver: Factors Which Promote Response

Six factors have been discovered which appear to shape the public's receptivity to warnings. First, and perhaps most important, the characteristics of the emergency sometimes do not match the receivers' observations. It would not be surprising if the credibility of a warning suffers in the event a flood prediction is made while the receivers were enjoying a sunny day. Environmental cues are important elements in anchoring the threat. In the event that environmental cues are inconsistent with the threat, warnings can be accompanied by artificial triggers, such as sirens. Environmental cues have been found to be an important ingredient in promoting hurricane evacuations; populations often wait until weather changes are observed before taking protective action. Second, social setting plays a role in sensitizing the receiver. Whether the family is together, the activities engaged in at the time of warning, and the behavior of others (friends and neighbors) all combine to influence beliefs, decisions, and ultimately response (Drabek, 1969).

Third, social ties such as family cohesion can work to foster a decision to evacuate. It is easier to relocate with a family member than to be temporarily sheltered in an institution. Fourth, social status, gender, income class, and age play a role. Age is related to hearing, believing, and behavior. Older people have been shown to be less likely to hear a warning regardless of source and women tend to be more likely to believe a warning than men (Mack and Baker, 1961).

Fifth, cognitive abilities, personality, or attitudes can influence reception. Information overload can preempt protective actions. Locus of control, that is, whether people believe they control their own destinies or are subject to the fickle nature of fate, alters warning response in ways the reader might anticipate. Responders who are internally directed are more likely to respond to a warning (Perry, 1979).

THE VALUE OF KNOWING HOW THE PUBLIC IS LIKELY TO RESPOND

Being able to predict how people are likely to respond to a potential warning about the failure of a high-hazard dam is an essential element in any risk analysis. The options for reducing loss of life go beyond structural improvements such as elevating the dam. In some instances it may prove to be more efficient to enhance the effectiveness of evacuations. The decision as to which strategy to pursue is ultimately a political one. However, in the wake of Gramm-Rudman mandated cuts in federal spending, economic efficiency has taken on new meaning. It is obvious that the problem posed by unsafe dams will not be dealt with immediately. As a result, the Corps may be forced to attack the problem in a piecemeal fashion, concentrating on the most hazardous locations first and relying on less expensive means to cope with the rest. Without knowledge about the effectiveness of the current warning system, it is impossible perform a satisfactory risk analysis or, for that matter, to evaluate the effectiveness of any improvements. Simplistic assumptions found in some of the literature regarding human response is at best naive and at worst seriously misleading.

Given the lack of alternatives, it appears that the procedure for estimating the loss of life outlined in "Interim Procedures for Evaluating Modifications of Existing Dams Related to Hydrologic Deficiencies" is a reasonable starting point. However, uncertainties about lead time and the effectiveness of warnings could be lessened by developing more elaborate loss-of-life equations (U.S. Army Engineer IWR, 1986; eq. 3.1 and 3.2, p. III-48) which are sensitive to sender/receiver characteristics outlined in Chapter II. The resulting relationships could then be used to assess the combined effects of structures, land use, and warnings on loss of life.

VI. CONCLUSIONS AND RECOMMENDATIONS

This review has covered a range of theoretical and empirical research. It has cut across disciplines as well as hazards. At this stage we are left with impressions and judgments about how risk analysis might be improved, what might be deemphasized, and what requires additional attention. The following remarks are brief but direct.

1. Risk analysis methodology has evolved to a degree of sophistication which far outpaces the data required for its implementation. The concepts inherent in risk analysis methodology would be a valuable guide to practitioners when and if simplified (see Pate-Cornell and Tagaras, 1986, for an example). The development of sophisticated techniques for weighting multiple objectives has advanced the prospects of conducting meaningful benefit risk trade-offs. However, it should be noted that many of the problems which have plagued economists in their attempt to elicit the public's willingness to pay for safety are also inherent in the surrogate worth trade-off method. Additional work needs to be done to ensure that the survey instruments used are as free as possible from the biases which contingent valuation method research has recognized for some time.

2. Risk analysis is based on the probability of a flood event, the probability that a dam fails, given that event, the probability that the failure is detected, and the probability that warnings are both issued and produce the desired reaction. Too often, risk analyses focus on the likelihood of the triggering mechanism occurring and ignore the difficulties in ensuring a timely evacuation. Such a practice understates the chances of truly catastrophic loss of life. It may appear from the review of the warnings literature that there is much confusion about what constitutes a good warning system. This is not true. The elements of an effective warning system are known and can be implemented. Chapter V does point out that warning systems may fail for a wide variety of reasons. A risk analysis which is conducted without reference to this literature is likely to understate the risks of true catastrophe. Likewise a benefit-cost analysis which fails to reflect the potential that warnings hold for saving lives and property will produce suboptimum solutions.

3. It is clear from both theoretical and empirical research that the so-called secondary losses produced by a disaster have been overstated. Employment effects could be of pivotal concern if a region's primary industrial base was at risk or a significant

percentage of a region's capital stock was situated in the floodplain. Barring these possibilities, it seems safe to ignore secondary loss.

4. There is evidence to link mental health with the occurrence of disaster. However, this relationship could be overstated. The Corps' own efforts to quantify psychological impacts require more sophisticated and realistic indices than have heretofore been employed.

Relatively little funding has been earmarked for the socioeconomic aspects of risk analysis, at least in contrast to the amounts expended on refinements of risk assessment methodology, improving precipitation probability estimates, and better understanding the mechanism of dam failure. There is serious question, however, as to whether the resulting probabilities are of sufficient accuracy. More important, the risks to life and limb hinge on another set of probabilities, i.e., warning time and response. To our knowledge no one has attempted a risk assessment which incorporates the chances of a warning system working as planned. As was shown in Chapter V there is ample evidence to show that a completely successful warning and evacuation is the exception rather than the rule.

APPENDIX A:

A GENERAL EQUILIBRIUM MODEL FOR MEASURING DISASTER LOSSES

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A GENERAL EQUILIBRIUM MODEL FOR MEASURING DISASTER LOSSES

The strategy employed in this appendix is based on these earlier efforts. In contrast to Whalley (1975; 1977) and Kokoski and Smith (1984), however, the model is simply pedagogical; no attempt was made to collect actual demand and production data.

General Assumptions Regarding the Availability of Information

The existence of an open and competitive regional economy is assumed. Despite its competitiveness, the participants are only endowed with partial information. They are assumed to know their preferences (consumers), production possibilities (firms), and the probability of different states of nature. They are not subject to illusion of any sort. That is, the heuristics, which Kunreuther (1984) and Kahneman, Slovic, and Tversky (1982), among others, have argued guide decision makers in their struggle with risky situations, are assumed away. The one attribute that cannot be granted, however, is perfect knowledge regarding the other decision makers. Their choices are revealed through the market process alone. The results of their decisions are reflected in the economy's vectors of price and output. Hence, the degree of protection raw material suppliers have afforded their own production processes remain known to them and them alone. The demanders of these products are aware of the price they must pay for their inputs, no more.

The Production Sector

The economy is assumed to be comprised of a set of n producers, each of which faces a constant elasticity of substitution (CES) production function, equation (A1) in Table A-1. Each sector, j, produces a good which is either an ingredient in another production process or is sold directly to households. Labor (l_j), capital (k_j), and other raw ingredients ($a_{i,j}$), are combined to create good j. Rho measures the ease with which labor can be substituted for capital while maintaining constant output. The larger its value, the more difficult the substitution becomes. At the extreme, an infinite value yields a fixed coefficient model similar to that embodied by the Leontief approach. At the other extreme, a value of 1 implies that resources can be substituted easily (the elasticity is infinite). In between (rho equals 0), the elasticity is -1, meaning that a 1 percent change in one ingredient requires a 1 percent offsetting change in the other in order to maintain output. This also happens to be the elasticity of another commonly used production function, i.e., Cobb-Douglas. The reason for selecting the CES form should be evident from its flexibility. It permits experimentation to determine the effects of variation in factor substitutability on the magnitude of secondary losses.

$\alpha_{i,j}$ is a matrix of technical coefficients which reflects inputs other than capital and labor. They are assumed to be utilized in direct proportion to the quantity of goods produced in process j. Hence, this production process is a hybrid. It permits substitution with regard to capital and labor but fixes intermediate production. See Reif (1981) for a detailed discussion of the approach.

The price received for good j is determined through market forces and is therefore a product of the combined effects of supply, consumer preferences, and household income. Firms are price takers. The costs of raw materials per unit of production are introduced by subtracting their prices (adjusted by their contribution to output) from the final product price. See equation (A2), Table A-1.

Producers are assumed to maximize profits by equating the value of the marginal product of labor and capital to their respective costs, shown as equation (A3), Table A-1.

Labor rates are assumed fixed in order to determine the base vector of prices, outputs, employment, and capital stock. This means that in the very long run, labor supply is infinitely elastic with respect to real wages. In fixing wages they became a numerare against which all other prices could be compared. In the short-to-intermediate run, that is, throughout the reconstruction period, the supply of labor was assumed to be perfectly elastic with respect to nominal wages up to full employment but perfectly inelastic at full employment.

In specifying the shape of the labor supply function independent of consumption, the effects of the disaster are likely to be incorrectly stated. Although the error is unlikely to be large, it is worth discussing. Households balance more than just consumption against income; utility is derived from leisure as well. Just, Hueth, and Schmitz (1982, pp. 390-393) discuss a method of dealing with this problem by suggesting the existence of a pseudoexpenditure function which can be differentiated with respect to the wage rate to obtain a compensated labor supply curve. Such a curve corresponds to the compensated leisure demand, from which a compensated variation of a wage-price-income change can be determined. "Thus, the compensating (equivalent) variation for a general wage-price-income change is uniquely measured by adding the change in exogenous income, the change in area left of the compensated labor supply, plus all the changes in the areas left of compensated demands for consumption goods, where each demand or supply is evaluated at the initial (final) utility level, but successively conditioned on previously considered wages and price changes" (Just, Hueth, and Schmitz, 1982, p. 392).

TABLE A-1

PRODUCER EQUATIONS

Production Functions

Eq. (A1) $Y_j = (a_{0j} + a_{1j}\ell_j^{-\rho j} + a_{2j}k_j^{-\rho j})^{(-1/\rho_j)}$

where

a_{0j} is a parameter reflecting returns to scale (set to zero for this study, i.e., constant returns to scale)

a_{1j} and a_{2j} are share parameters

ρ_j reflects the elasticity of substitution (ℓ for k)

ℓ_j is labor units employed in industry j

k_j is the capital stock of industry j.

Net Price

Eq. (A2) $PNET_j = P_j - \sum_{i=1}^{n-1} \alpha_{i,j} * P_i$

where

P_j is the market price of good j

$PNET_j$ is the price received for good j net of price paid for input i

$\alpha_{i,j}$ is the number of units of i required per unit of j produced.

P_i is the price of input i

First Order Condition for Maximizing Profits

Eq. (A3) $\frac{\delta \underline{Y}_j}{\delta j} * PNET_j = \bar{w}$

where $\bar{w}$ is the full employment wage rate.

Eq. (A4) $\frac{\delta \underline{Y}_j}{\delta kj} * PNET_j = r * Pc$

where r is the interest rate

Pc is the price per unit of capital.

Labor Market: Market Clearing Condition

Eq. (A5) $L \geq \sum_{j=1}^{n} \ell_j$

where L is full employment.

Secondary Capital Market

Eq. (A6) $k_j = k_j^0 - k_j^1$ $\left\{ \begin{array}{l} \text{demander of capital + provider of} \\ \text{capital to secondary capital market} \end{array} \right.$

where k_j^0 is firm j's predisaster stock of capital

k_j^1 is firm j's postdisaster demand for capital.

Capital Markets--Primary and Secondary Markets

One sector of the economy was designated as the producer of capital goods for all the other producing sectors and for households. Its capital stock was assumed to be exogenously given and not easily expanded as a result of a sudden shift in demand. This assumption implies the existence of an adjustment cost proportional to the magnitude of the task of reconstruction. The combination of the investment goods industry's capital stock being fixed, and the fact that it employs a CES production technology in which labor and capital are not perfect substitutes result in a rising supply price of capital. The extent to which this occurs depends on the magnitude of the disaster and the strains placed on this one sector. The market clearing price of capital is a product of both consumer and producer demands. How much is sold for final consumption and how much is provided to other industries are assumed to be determined by market forces alone. If consumers are willing and able to pay the going price, they will successfully bid capital in the form of durable goods and housing away from business. However, in so doing, the ability of these industries to produce other consumer goods, which might enter the utility function, would be impaired. Just as important, an industry's inability to replace damaged capital would translate into regional income losses. Given that the product demands are income elastic, the consumer's ability to absorb much of the capital goods industry's product would be limited.

It should be noted that a disaster would likely produce an uneven pattern of damage. Some industries might be untouched while others are devastated. As the economy rebalances, as incomes and relative prices shift, some sectors would find demands for their products to be slack. In such instances an excess supply of capital would materialize. It is assumed that capital is malleable enough to be utilized by any sector without diminution of productivity. A secondary capital market is postulated which provides those industries with excess capacity the opportunity to "lease" capital to those who find it profitable to replace damaged stock, equation (A6), Table A-1. The going lease rate is assumed to be equivalent to the price of newly produced capital. Such interindustry transfers have no net effect on regional income. They do, however, provide the proper signals for capital flows, which in turn shape the nature of the postdisaster pattern of production and associated prices.

A Brief Digression on Adjustment Costs

These adjustment costs play a key role in the analysis to follow. In order to avoid confusion later in the paper, the underlying assumptions on which this concept is founded are discussed at this stage. The idea that capital costs might be sensitive to the speed with which economic expansion takes place can be traced to Keynes (1936). In the general theory, Keynes draws a distinction between the marginal efficiency of capital and the marginal efficiency of investment, pointing out that "If there is an increased investment in any given type of capital during any period of time, the marginal efficiency of that type of capital will diminish as the investment in it is increased, partly because the prospective yield will fall as the supply of that type of capital is increased, and partly because, as a rule, pressure on the facilities for producing that type of capital will cause its supply price to rise" (p. 136). Lucas (1967) provided a more rigorous formulation of the problem. The object of these studies was to demonstrate that a rapid demand shift could produce adjustments which might not be predicted by traditional neoclassical theory. The framework also provided a rationale for the distributed lag models of investment behavior widely utilized at the time.

These analyses share a common structure. Lucas, for example, assumed that a firm's production function depended not only on the mix of capital and labor employed but also on the rate of addition to the capital stock. This might appear to be _ad hoc_ at first, but he explains that time might be required to absorb new capital; it might be less productive at first and learning may be involved. In any event, the technique also yields a cost function which depends on the rate of change in the capital stock. The firm is then assumed to maximize the discounted value of its net receipts over an infinite planning horizon.

One troublesome point, which clearly is not resolved in any of these articles, is the availability of information. What future prices and capital costs can a producer anticipate? Lucas manages the question by assuming "static expectations," that is, decision makers are led to believe that current prices will persist regardless of experience. More elaborate schemes for incorporating price information, such as rational expectations, have been conceived. However, the more realistic the assumptions regarding producer knowledge, the more complicated the model.

These models provide a foundation for the framework developed here. However, there are some striking differences. First, most of adjustment cost literature was motivated by increased demand for capital services. Such is not true here, at least initially. A supply shock is the triggering mechanism. Second, Lucas chose to focus on a single industry, disconnected from suppliers and households. This leads to an assertion that demand for an industry's products is exogenously given, as is the rate of change in that demand.

The approach taken in this paper differs from that just described. Households are included in the analysis. This permits price ratios to shift as consumers and producers struggle to balance production and consumption plans during the postdisaster period. Demand for products is also assumed to be income elastic. Hence, the rate of capital formation is determined by the speed with which the economy rebounds from the disaster which, of course, is tied to net investment. The recursive nature of this relationship is described below. Lastly, it is a fact that the effects of disasters are seldom spread uniformly. Pockets of total destruction might be observed bordering areas of light to moderate damage. Hence, the potential for a secondary capital market exists, where owners of undamaged equipment and structures can capture rent by leasing surviving capital for uses other than that for which it was originally intended.

Aside from the basic concept of adjustment cost which, in its modified form, is still key to the conclusions of the paper, the only other similarity between this approach and that developed by Lucas (1967) is reliance on static expectations. It is clear that equating the capital's value of the marginal product with its marginal cost (adjustment costs included) could be unwise. The prices which a firm may wish to utilize in estimating its own internal rate of return might prove to be transitory. If so, an ex post rate of return may be quite a bit lower than what would be anticipated as a result of employing static expectations. But, what behavioral rule makes sense? In the case of disasters, not only are prices time dependent, they are decision dependent as well. It could be shown that at least one investment path will exist to maximize the value of the community's firms. It is unlikely, however, that decision makers will be privy to the information required to establish such a path.

The question of expectations goes far beyond the objectives of this paper. Hence, further consideration of this highly complex and interesting issue is at least temporarily set aside.

Households--Decisions Regarding Consumption and Saving

Traditional consumer theory forms the basis of consumer choice. It is assumed that all households exhibit similar preferences for commodities. Such preferences are expressed by a well-behaved utility function which is both quasi concave and increases with income, albeit at a decreasing rate. The Stone-Geary function, shown in equation (A7), Table A-2, incorporates both of these requirements. The fact that this form exhibits diminishing marginal utility as a function of income makes it especially useful. However, it is a variant of Cobb-Douglas, and therefore the elasticity of substitution is restricted to a single value. The gammas in equation (A7) may be interpreted as minimum subsistence quantities, whereas the betas are share parameters.

Consumers are assumed to maximize the utility received as a consequence of consumption. That is, they implicitly select a market basket of goods which maximize equation (A7) subject to a budget constraint. Spending on all k goods must equal the disposable income available for purchases. This amount is gross income less taxes and savings; the marginal propensity to save is assumed to be determined exogenously. It is of course true that decisions regarding consumption, saving, and labor supply are made simultaneously. As in the case of labor supply, this theoretical fine point is overlooked.

TABLE A-2

CONSUMER EQUATIONS

Utility

Eq. (A7) $U = \sum_{i=1}^{k} [\beta_i * \ln(yd_i - \sigma_i)]$

where
k is number of commodities
β_i is weight given to commodity i
yd_i is amount of good i consumed
σ_i is the minimum amount of good i acceptable.

Marshallian Demand Curves

Eq. (A8) $yd_i = \sigma_i + (\beta_i/P_i)\ (y_{disp} - \sum_{i=1}^{k} P_i\sigma_i)$

where
y_{disp} is household income devoted to consumption.

Regional Income Constraint

Eq. (A9) $Y_{tot} = [\sum_{j}^{n} (\ell_j \bar{w}) + (k_j^0 * Pc^0 * r) + (\Delta k_j Pc' * r) + \pi_j]$

where
n is the number of producing activities
ℓ_j is the labor employed in sector j
$\bar{w}$ is the wage rate in each sector (assumed equal)
k_j^0 is the initial long run capital stock
Pc^0 is the initial supply price of capital
r is the rate of interest
Δk_j is net investment in sector j
Pc' is the post disaster supply price of capital
π_j is the profit earned by j.

Savings

Eq. (A10) $S = (1 - mpc)\ Y_{tot} * (1 - t) + R$

where
S is consumer savings
MPC is the marginal propensity to consume
Y_{tot} is regional income (wages, interest, and profits)
t is the tax rate
R is government disaster payments.

The Marshallian demand functions used in the model were obtained directly from the optimization just described. See equation (A8), Table A-2. Yd_i represents the quantities demanded, given household income and the relative prices of the respective i goods. Since these expressions reflect the result of utility maximization, they provide a basis for measuring the loss of utility that might be observed in the wake of a disaster. The postdisaster compensation required to reestablish predisaster utility would be a good measure of the degree to which the victims' welfare has changed. It will be argued in a latter part of the paper that this payment is the true measure of disaster loss.

Since workers finance, own, and provide the labor to the producing units, they also receive all the income. This permitted the adoption of a single utility function. It would not be difficult to extend the model so as to reflect a number of consuming groups, blue-collar workers, and management, for example. See Whalley (1975). It is unlikely that a refinement such as this would yield insights which could not have been reached without the model. The distributional implications of disaster are important elements of welfare. The consequences of varying ownership (inside and outside the region) are briefly discussed in the concluding section.

Regional income is described by equation (A9). It is the sum of wages, interest, and profits. Interest income is derived from both the existing capital stock and new investments. It is assumed that once capital is destroyed, interest payments are terminated. The effects of a disaster could just as easily have been captured by reducing corporate profits by a like amount. The former was adopted for computational convenience. R is the amount of external aid provided the region.

Trade

It is assumed that the disaster-stricken region is tied to the rest of the world through import and export markets. The elasticity of demand expressed by the rest of the world for the region's products plays a role in shaping recovery. The greater the elasticity, the more likely these export firms will voluntarily cash in the quasi rents which could be earned on capital undamaged in the disaster. In the event export demand proves to be inelastic, one might expect producers to release a small amount of capital which in turn would dramatically boost export prices. The profits would be plowed back into the economy in the form of consumer demand for regionally produced goods, which would stimulate markets within the region. The export equation is provided in Table A-3, equation (A1[illegible]).

The market for imports plays an equally important role. It is assumed that the supply of imports would be infinitely elastic at a price greater than that observed within the region. If, however, prices within the region rise vis-a-vis the rest of the world, imports

TABLE A-3

GOVERNMENT, TRADE, AND REGIONAL BUDGET CONSTRAINTS

Government
Spending

$\overline{G}$

Taxes

Eq. (A11) $T = t * Y_{tot}$

Trade
Imports

Eq. (A12) 0 if $P_j \leq P_{imp}$
Y_{impj} if $P_j > P_{imp}$

where $Y_{impj} = SL_{imp} (P_j - P_{imp})$
Y_{impj} is the quantity imported
P_{imp} is the price of imported goods
SL_{imp} is the slope of imported function

Exports

Eq. (A13) $Ex = h - m * P_x$

where h and m are parameters of a linear demand function
P_x is the price of exports.

Regional Budget Constraint

Eq. (A14) $S + T + \sum_{j=1}^{n} Y_{impj} * P_j = \sum_{j=1}^{n} (G_j * P_j) + (Ex * P_x) + INET$

where

INET is net investment across all sectors (wage units)
$G_j * P_j$ is government spending (wage units) for good j
$Y_{impj} * P_j$ is the value of imports (wage units).

---

could be expected to flow into the affected area in proportion to this price differential. The slope of the import response function shown in equation (A12) is equivalent to the price elasticity of supply. A differential in production costs could be explained by transportation charges or by a limited external supply.

Government

Local government competes with both industry and consumers for capital goods, particularly in the form of construction services. It is assumed that it must pay the going market price and that the government's demand for capital is uninfluenced by prices or the occurrence of the disaster. It is important to note, however, that the destruction of public capital, e.g., roads, bridges, etc., would affect private sector production. Since the CES functions utilized in the study do not reflect these and like public facilities, the supply-side effects of government programs are ignored. The demand effects were confined to the maintenance of a predisaster level of spending. By itself, this would tend to crowd out new investment and private sector consumption. The inclusion of damage to social capital would serve to boost the consequences of the disaster in terms of regional welfare and prolong the period of recovery. Higher levels of compensation would be required to reattain the predisaster level of material well-being.

Accounting Identities

All markets are assumed to clear throughout the period of reconstruction.

$$S(P_i) = D(P_i)$$

This could be a troublesome assumption in that it is unlikely that price adjustments will be as rapid as implied by the equality. Planned purchases and production would in all probability diverge from that realized. The resultant quantity adjustments, particularly in the form of inventory accumulation, could lead to a lengthier and more costly set of dislocations than anticipated as a result of applying the tools of general equilibrium. See Clower (1967) and more recently Reif (1981) and Barro and Grossman (1976) for a more detailed discussion of exchange under nonmarket clearing conditions. However, once again the principles which are the focus of this paper will not be affected by such considerations. If anything, the inclusion of quantity adjustments discussed by Clower would only serve to reinforce the paper's conclusions.

Savings are derived directly from the household's disposable income. No attempt was made to make this decision endogenous. The utility function portrayed in equation (A7), Table A-2, is shown to be a function of the quantities consumed and income only. Disaster-induced wealth effects would, of course, play a role. The destruction of capital values would force some households to reallocate resources over their life cycle. One would expect current welfare to suffer and savings rates to rise. Such intertemporal adjustments would tend to prolong the effects of the disaster, raising the required level of compensation.

The amount of tax collected is a fixed proportion of the region's total income. Government spending is not tied to tax receipts, although that could easily be done. As a result, savings need not equal net investment nor imports equal exports. However, the sum of savings, taxes, and imports must equal government spending, net investment, and imports. This ensures that income is fully allocated. See equation (A14), Table A-3.

The Regional Model Clarified

The supply of goods and the incomes which that supply represents must be allocated to either consumer spending, investment, government spending, or net exports. Put simply, regional income is equivalent to the supply of regionally produced goods and services. To this one must add (1) the supply of imported goods to obtain the total value of goods and services available to businesses in the form of investment (plant and equipment), (2) government to maintain schools and provide other necessary public services, (3) consumers and producers in other regions, and (4) consumables and residential structures for local households. This constraint simply means that the value produced must be accounted for. The relationship also points out that in any year the government's budget need not be balanced (spending could be greater or less than tax revenue). The same applies to imports and exports and investment and savings. The numerical example utilized below contains an export sector but no imports. If the government's budget is balanced the value of exports is added to savings. This, of course, cannot continue forever; local residents will eventually wish to spend their accumulated savings, most likely on goods and services produced elsewhere. Hence, the imbalance shown in the numerical example could be observed in the short-and-intermediate run, but not in the long run.

A Summary of the Assumptions

Even simple models involve a number of assumptions which could bias results. Table A-4 is provided for the reader's convenience; it briefly summarizes the most important of these. In most instances the biases, if present, act to reduce the secondary effects and period of recovery.

TABLE A-4

GALLERY OF ASSUMPTIONS

1. Production functions for each sector are CES, homogeneous degree one.

2. The utility function is Stone Geary. The disaster is assumed to leave the consumer preference map unchanged.

3. Intermediate goods are used in fixed proportion to the quantity of the final good produced.

4. The local government is not required to balance its budget. The income tax is the only form of tax revenue. The level of local government spending is exogenously given and is not influenced by the disaster. Disaster aid is provided from federal sources.

5. The financial capital requirements of the disaster-stricken region are assumed to be small relative to the national credit markets. New investments within the region are assumed to be no more risky (given maturity and type of industry) than similar issues in unaffected regions. Hence, interest rates are assured to be uninfluenced by the disaster.

6. Exports are determined by a linear demand curve. Incomes in regions which rely on the disaster-stricken area for their source of supply are assumed to be negligibly affected by production changes. It is assumed that only final goods are exported, hence, welfare losses (measured as a reduction in consumer surplus) may be sustained in the event production costs, and hence prices, rise. It is assumed that prior to the disaster, producers located elsewhere were at a competitive disadvantage in terms of selling products within the region. This might be due to the presence of transportation costs or product differentiation. However, once the disaster occurs and the regional price of products rises, imports are triggered. The import supply function is not perfectly elastic.

7. Consumers are assumed to save a constant proportion of their income regardless of income level.

8. Physical capital used to produce intermediate and final goods is malleable. Physical capital used to produce new capital is fixed.

TABLE A-4 (Continued)

9.	Wages are used as a numerare.
10.	The labor supply function is assumed to be perfectly elastic up to full employment and perfectly inelastic beyond that point. Factory owners are subject to money illusion, i.e., they focus on nominal as opposed to real wages, interest, and prices.
11.	The producer units are assumed to be worker owned. All factor income is retained by households residing within the region.
12.	Disaster aid is paid to the victims in direct proportion to the losses sustained.
13.	The disaster is assumed to only affect material goods.
14.	Firms are assumed to maximize profits throughout the period of reconstruction.

AD-A186 149 SOCIOECONOMIC CONSIDERATIONS IN DAM SAFETY RISK ANALYSIS(U) PLANNING AND MANAGEMENT CONSULTANTS LTD CARBONDALE IL H C COCHRANE ET AL. JUN 87 IWR-87-R-7 2/2

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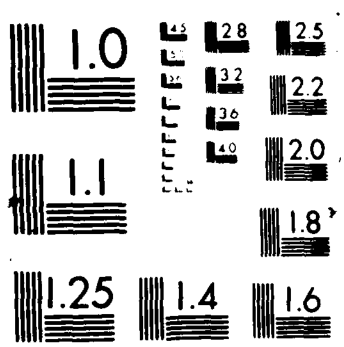
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COUNTING THE LOSSES

Immediate Postdisaster Compensation

The utility function which underlies consumer choices and which guides their spending in the wake of a disaster is of course not directly measurable. An observable alternative for assessing the intensity of avoiding a state of disaster is the amount of money the individual is willing to pay or accept to prevent the outcomes. Recall that the only states of the world which are entertained in this paper are those which influence consumption. Hence, the approach which is developed here will understate the required compensation to the extent society wishes to prevent loss of life, deterioration of health, and the destruction of irreplaceable assets. Annual compensation (AC) is the minimum annual transfer payment a person would require as compensation for experiencing the effects of a disaster, given that both prices and incomes could change.

Eq. (A15) $AC = R$ given: U_0, P_1, Y_{tot}

where

P_1 is the postdisaster vector of prices;
R is the disaster payment made to the region to compensate for lost welfare;
U_0 is the predisaster level of welfare;
Y_{tot} is the postdisaster level of income (excluding interregional transfer payments).

Such effects will take two forms: a loss of purchasing power as a result of destruction of physical capital and a revision of relative prices as a result of a reallocation of productive resources to their most highly valued uses. The magnitude of compensation hinges on the elasticity of substitution of one commodity for another, the mobility of labor and capital, and the technical elasticity of substitution in production.

What is the compensating variation in this case? Is it safe to use the postdisaster price vector? Is compensation paid or is it not paid? Hicks (1956) defines compensating variation (CV) as the minimum amount by which a consumer would have to be compensated after a price change in order to be as well off as before. It is conventionally argued that compensation need not be paid, since CV is utilized to determine the level of potential benefits produced by a public project. All that matters is that winners are able to compensate the losers; whether they do or not is thought to be of little consequence from the standpoint of economic efficiency. Hicks could ignore production effects, since he was concerned primarily with consumer behavior. Theorists were safe in assuming that a project which induced a price change would not result in major shifts in production. That is, the project under investigation was assumed to be minor in contrast with the national economy. This is not true here, however. Compensation, if paid, will exacerbate bottlenecks, thereby producing a more rapid increase in the supply price of capital and inducing a greater reliance on imports. The payment of compensation increases the amount of compensation required, a point which is likely to be spark some debate. Regardless, a convincing argument may be made that the correct measure of compensation is one which includes the effects of its payment. Whether it is actually paid is irrelevant.

Establishing a value for the compensating variation proved to be much easier in this paper than would likely be the case in practice. The utility function was postulated. Hence U_0 was known with precision. As a result, it was a relatively simple matter to backsolve the model to determine the disaster payments required to reestablish predisaster welfare (U_0). In practice estimating CV is not so simple; see Kokoski and Smith (1984) for a recent example.

It should be noted that the welfare measure just described captures the effects on the disturbed region alone. To the extent that imports and exports are involved, losses (gains) might be sustained in neighboring regions. The model may be readily extended to cover this possibility as well as the others discussed previously.

The Process of Rebuilding: The Intertemporal Nature of Annual Compensation

In the event that the entire stock of capital cannot be replaced in a single period, compensation must be recomputed in succeeding periods until the process of reconstruction is complete. The true loss is the discounted stream of annual compensation (AC) shown in Figure A-1 and equation (A16).

Eq. (A16) True Measure of Loss $= AC(K_t)/(1+r)^t$

where

$AC(K_t)$ is the annual compensation computed given the stock of capital, K_t, at time t;
r is the discount rate; and
$K_t = K_{t-1} + I_t$.

For larger disasters, where frictions cannot be ignored, annual compensation can be expected to attenuate as shown in Figure A-1, Curve A. The extent of destruction is too vast for rebuilding to be completed within a single period. As the capital stock expands, adjustment costs decline, higher-priced imports are replaced by less expensive goods produced within the region, the rate of unemployment drops, and the annual compensation diminishes accordingly. See Figure A-2 and Figure A-3 of the same page. If the damage is a relatively small proportion of the region's productive capacity, adjustment costs are likely to be minimal and the path of annual compensation would attenuate more

FIGURE A-1

POTENTIAL PATTERNS OF ANNUAL COMPENSATION

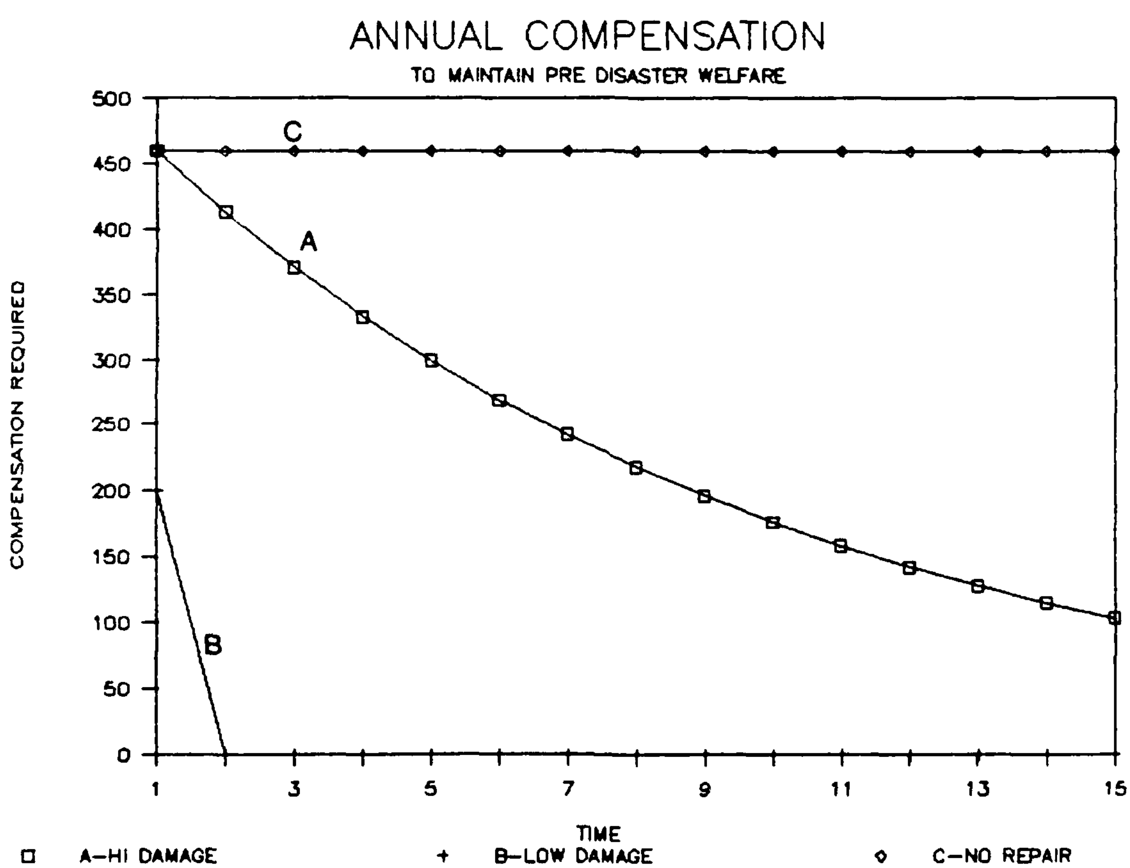


FIGURE A-2

CAPITAL STOCK RESTORED

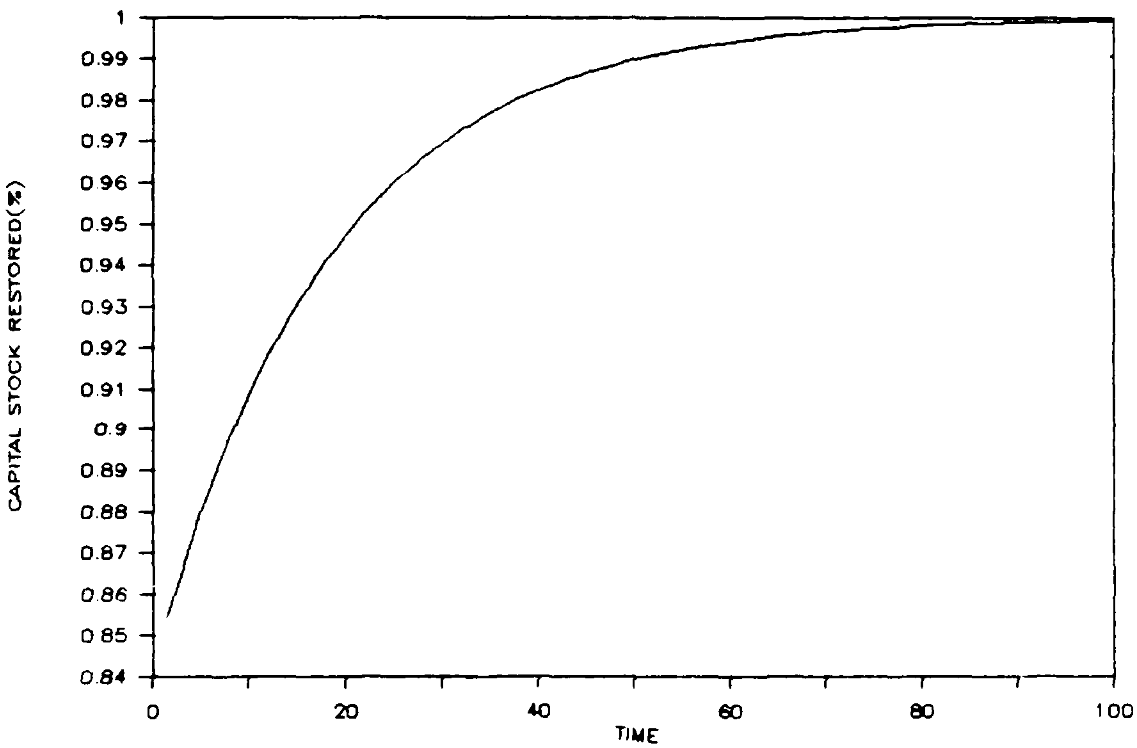
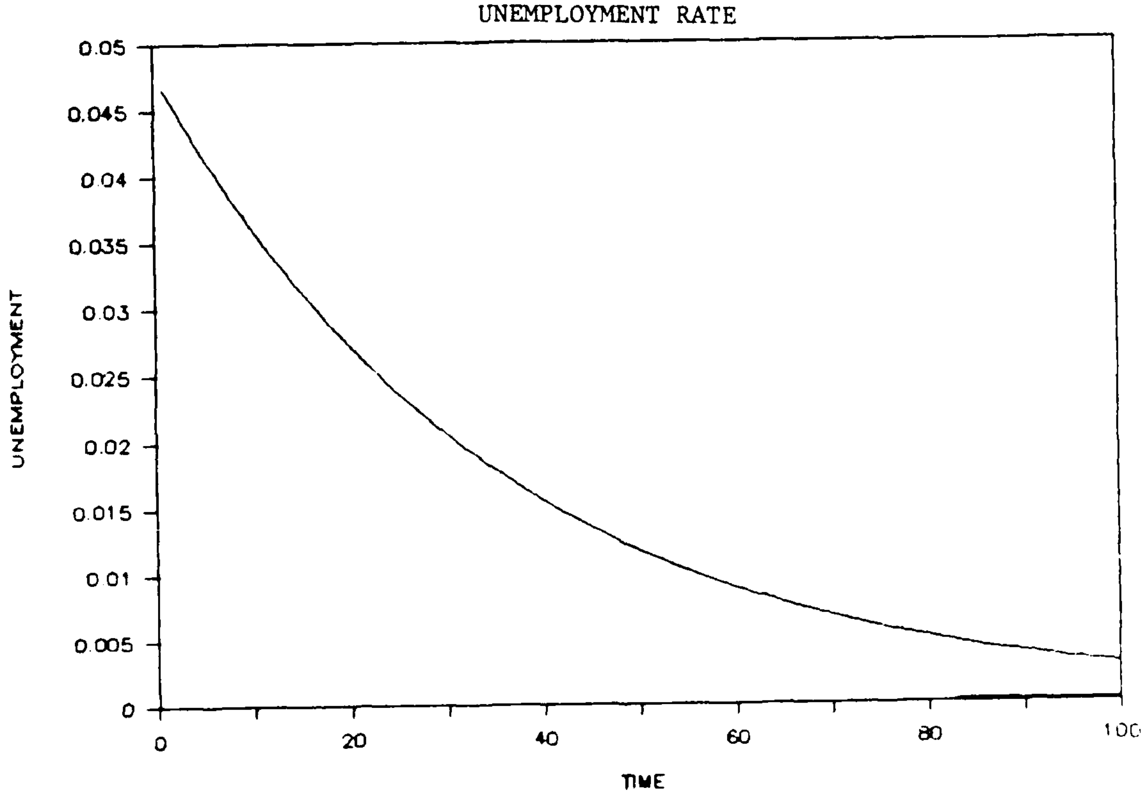


FIGURE A-3
UNEMPLOYMENT RATE



rapidly; see Figure A-1, Curve B. Curve C depicts a final possibility, which could occur if the damaged industry finds that it is economically infeasible to rebuild.

It is important to note that under certain circumstances, the true measure of loss (equation (A16)) is equivalent to the value of capital destroyed. For example, if no adjustment costs are encountered, that is, if the damaged capital is restored instantaneously at no additional expense, then compensation to the owners of the capital would be the equivalent of the value lost. Adjustment costs are typically dismissed as "friction." However, as we have just seen, it is the presence of this "friction" which results in the secondary losses about which so much has been written, and so much confusion has swirled.

At least in this one instance, Roberts, Milliman, and Ellson (1982) are correct in stating that the addition of capital and income losses involves some double counting. In fact, according to Curve B in Figure A-1, the losses would be counted exactly twice, once in the category of direct property damages and again in the discounted income lost to the owners of the capital, which was shown to be equal to the damages. However, this is the only instance for which double counting is so easily identified. The greater the disaster, the greater the potential that bottleneck costs will accentuate losses, thereby producing pure secondary effects. Several experiments were conducted to determine the potential magnitude of these effects, some producing results countering the conclusions reached by Roberts et al.

HYPOTHETICAL EXAMPLE

Background

The following highly stylized example serves as a backdrop to highlight the issues inherent in the measurement of economic losses. The primary focus of the example is the appropriate method for counting both direct and indirect economic damages which could result from a catastrophic failure of a high-hazard dam. To keep the problem manageable, complications such as loss of life, so-called psychological trauma accompanying the stress induced by such an event, and the destruction of irreplaceable assets are at least temporarily ignored. These important considerations are addressed in a separate section. A simple economy is fabricated and used to simulate the effects of dam failure on damages, employment, material welfare, and the time path of economic recovery. The effects of altering assumptions regarding substitutability of labor for capital, the availability of competitively priced goods imported from other regions, and the provision of aid are explored through the use of a numerical general equilibrium system.

Setting for the Analysis: Bayes Dam

Bayesville, a rapidly growing city of 250,000, is located only ten miles downstream from what the Corps of Engineers considers to be a high-hazard dam (Bayes Dam). The land outside Bayesville's city limits is considered by many to be the most productive in the state. Much of this productivity can be traced directly to the abundant supply of water stored behind Bayes Dam.

Concern about the potential failure of Bayes Dam mounted after the occurrence of two unique and extreme weather events which, according to the state climatologist, had not previously been recorded. In June of 1984, and again in July of the same year, a severe stationary system of thunder cells, positioned over a minor catchment basin, resulted in 14 inches of rain over a 24-hour period. Had the events been separated by fewer than four days, or had either one formed over a major basin, the runoff would have exceeded Bayes' capacity, resulting in overtopping and subsequent catastrophic failure.

Surveys initiated in response to public pressure to ensure the dam's safety show that the potential area of inundation encompasses a major manufacturing facility. The plant in question is a major supplier of an intermediate product utilized by one of the region's final goods manufacturers. It is estimated that if the dam were to collapse, 15 percent of the plant's productive capacity would be destroyed. Ironically, no significant public capital (roads, schools, etc.) or private residential structures would be affected by the crest. The citizens of Bayesville, relieved about the security of their own possessions, were still concerned about the potential effects of losing a significant element of their industrial base. Specifically, they wished to know how such a disruption to the economy would affect employment, the prospects for rebuilding, and Bayesville's overall economic health.

The extent to which Bayesville is harmed can be measured by the payment which the citizens would be willing to receive to endure the effects of the failure. One might expect that they would have to be compensated by at least as much as the cost of the capital destroyed. To this must be added the costs of coping with the emergency and the impact on agricultural productivity as a result of losing half of the region's capacity to store runoff. Focusing on the manufacturing sector first, it is not clear that the level of compensation is so easily obtained. Recall that the manufacturing operation at risk supplies other facilities with a raw ingredient necessary to produce a final good for the Bayesville residents. If flood damage causes shortages to materialize, consumers might be affected indirectly and additional compensation might be required to reestablish the predisaster level of material well-being (utility).

The complexity of this simple problem balloons quickly once economic interdependence is introduced. Consumers would have to reevaluate the mix of products they wish to purchase given the likelihood that relative prices will shift in response to shortages of one or more products. The producers of consumer goods would be faced with the problem of reallocating capital and labor, as the postdisaster economy is out of balance from the standpoint of producer trading patterns and consumer demands. Some sectors would observe an excess supply of capital, while others (in the case, the industry damaged by the flood) an excess demand. If Bayesville's capital goods industry cannot expand rapidly, quasi rents will emerge in those economic sectors that possess undamaged plants and equipment.

The speed with which the economy rebounds depends on the amount of external aid funneled to the region, the competitiveness of imports which could substitute for the products affected by the flood, and the potential for substituting labor for the damaged capital. As pointed out above, required annual compensation could exceed the simple sum of direct damages. Relative prices and income effects resulting from production bottlenecks could contribute to AC as well. None of these effects, however, can be understood without including the entire set of producer/consumer interactions which comprise a market economy. The following general equilibrium model is provided to show the distinctions between the different categories of loss and to help resolve the discrepancies observed in the literature.

Parameter Values: The Predisaster Economy

The parameters for the production and utility functions were chosen to provide some flexibility with regard to consumer and producer substitutions. Beyond that requirement they do not carry any particular meaning beyond the interpretations normally attached to the functions shown in Tables A-1 and A-2. The matrix of coefficients reflecting the interindustry trade flows deserves some additional explanation since the hybrid nature of the model may be confusing. According to Table A-5, each unit of final good 2 (generic consumable) produced requires .5 units of good 0, the intermediate good. Accordingly, producers of this consumable cannot expand output without additional units of good 0. They are free to vary the combination of capital and labor according to the profit-maximizing rules set out in Table A-1. However, the firm's expansion path is constrained by the availability of intermediate goods. To keep the problem as simple as possible, the other industries are assumed to be not so constrained. Construction services (also the capital goods industry), good 1, are a product of labor and capital only. No intermediate goods are required. This of course is unrealistic, but it does simplify the computations and makes the results easier to interpret, without compromising the model's integrity. The cost of the intermediate good is treated simply by subtracting its price from the price of the consumable. The net price, the difference between the two, is the key which the consumable goods managers use in optimizing its mix of labor and capital and establishing an efficient scale of operation.

The trade sector is developed to highlight the potential interregional effects of a disaster. The linear trade export function is highly inelastic (.05), at the level of production which satisfies the set of equations. This means that good 3 is essential elsewhere and no ready substitutes are available. Industry 3 could be a semiconductor plant which produces custom microprocessors for specialized applications. It will be shown that this elasticity plays a role in shaping recovery and the compensation required to restore lost welfare. The base (predisaster) economy is conceived as self-sufficient; the region does not import goods and services. Imports do play a role during the postdisaster period in that they provide consumers the opportunity to continue consuming commodities which are unavailable from local manufacturers. The cost of these imports is higher than that produced locally, perhaps reflecting transportation costs. The postdisaster model includes an import function (Table A-3) which shows an increasing supply price with amount purchased. The slope of the response function, SL_{imp}, translates interregional price differentials into imports.[13] Table A-5 shows two values for SL_{imp}, 5,000 and 200. This extreme range was used to demonstrate how competition from other region could hamper rebuilding. A value of 5,000 means that for every one unit change in the price of good 2, 5,000 units of 2 would be imported.

Method of Solution

As simple as the model appears, it is still quite formidable in terms of computational requirements, since the functions are predominantly nonlinear. The model contains approximately 130 equations, many of which are identities and constraints. The decision variables are the labor and capital utilized in the four industries, imports, and the market prices associated with each product. Optimal consumer expenditures (reflecting maximum utility), income (wages and dividends), tax revenue, and levels of production are obtained directly from these results.

Numerical algorithms for solving models such as this have been available since Scarf's path-breaking work (Scarf and Hansen, 1973). Simpler approaches involving iterative procedures are less elegant, computationally less efficient, and require more attention from the user.[14] However, they are less expensive and more readily available.

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[13] The function used may at first appear <u>ad hoc</u>. Note, however, that the price of imports can be isolated and equated to a function of the disaster-stricken region's price and the slope, $P_j = P_{imp} + Y_{impj}/SL_{imp}$. The right side is a measure of the marginal cost of selling to the affected region.

[14] A great deal of care is required to ensure that the package converts. Inappropriate initial values, level of precision, and/or over/under identification could all produce error messages.

TABLE A-5

PARAMETER VALUES

Consumer Demands

	Gamma	Beta
Good 1	2,000	.35
Good 1	10,000	.65

Production Functions

	a_{oj}	a_{1j}	a_{2j}	ELAST. j	INELAST. j
Firm 0 (Intermediate goods)	0	.5	.5	0(1.0)	4(.20)
Firm 1 (Construction)	0	.25	.75	.9(.53)	6(.14)
Firm 2 (Consumer goods)	0	.75	.25	.5(.66)	7(.12)
Firm 3 (Export)	0	.2	.9	.9(.53)	7(.12)

Note: Elasticity of substitution is in parentheses.

Government

t	.2
g	80,000

Miscellaneous

Price of fixed capital	2,000
r Interest rate	.08
n Life of equipment	15

Regional Trade

Export Demand

h	5,000
m	.5

Import Supply

SL_{imp} (Elastic)	5,000
SL_{imp} (Inelastic)	700

Interindustry Coefficients

	Firm 0	Firm 1	Firm 2	Firm 3
Firm 0	0	0	.5	0
Firm 1	0	0	0	0
Firm 2	0	0	0	0
Firm 3	0	0	0	0

TK! Solver,[15] a package for the IBM PC which utilizes the Newton-Raphson procedure[15] for optimizing the search for a vector of values which meets a preset level of precision. This package proved to handle this problem with sufficient speed, permitting us to avoid the more sophisticated and, hence, more expensive numerical methods.

DISCUSSION OF THE RESULTS

Discussion of the Predisaster Structure of the Economy

The model was solved to obtain the predisaster vector of production, prices, and employment. The results were then transformed into a transactions table, Table A-6, in order to simplify the discussion. Note that since the economy is in momentary equilibrium, net investment and profits are zero. The gross regional product is 2.216 million units, which is equivalent to value added (imports are absent). The pattern shown in Table A-6 would continue indefinitely, unless households alter their demands, technology alters production costs, the import/export picture is reshaped, or government's fiscal policies or a disaster reduces the stock of capital available to the region. The predisaster welfare of the region is determined by the combination of good 1 and good 2 consumed. See Figure A-4.

The Effect of The Dam Failure

It was reported above that the failure of Bayes Dam would destroy 15 percent of the intermediate good's industry's capital stock. In the event that the damaged plant and equipment could be replaced instantly without incurring adjustment costs, the magnitude of the loss would be simple to estimate; it would equal the value of the capital destroyed.[16] However, instantaneous replacement is not economically feasible, given the fact that the steady state stock of plant and

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[15]The iteration produces a series of intermediate results that come to a desired solution. Each successive solution is found as a function of the previous one. The slope of the changes are recomputed and used to forecast values for the next iteration. The slope is given as [f(x + dx) - f(x)].

[16]Capital replacement is not quite as straightforward as indicated; new capital would most likely carry the advantages of newer production technology, hence vintage plays a role. Producers in the region might be utilizing older capital up to the point where it wears out or is destroyed. Market conditions may not permit its replacement. U.S. Steel, for example, never replaced steel-producing facilities damaged in the Johnstown flood.

TABLE A-6

PREDISASTER STRUCTURE OF THE ECONOMY

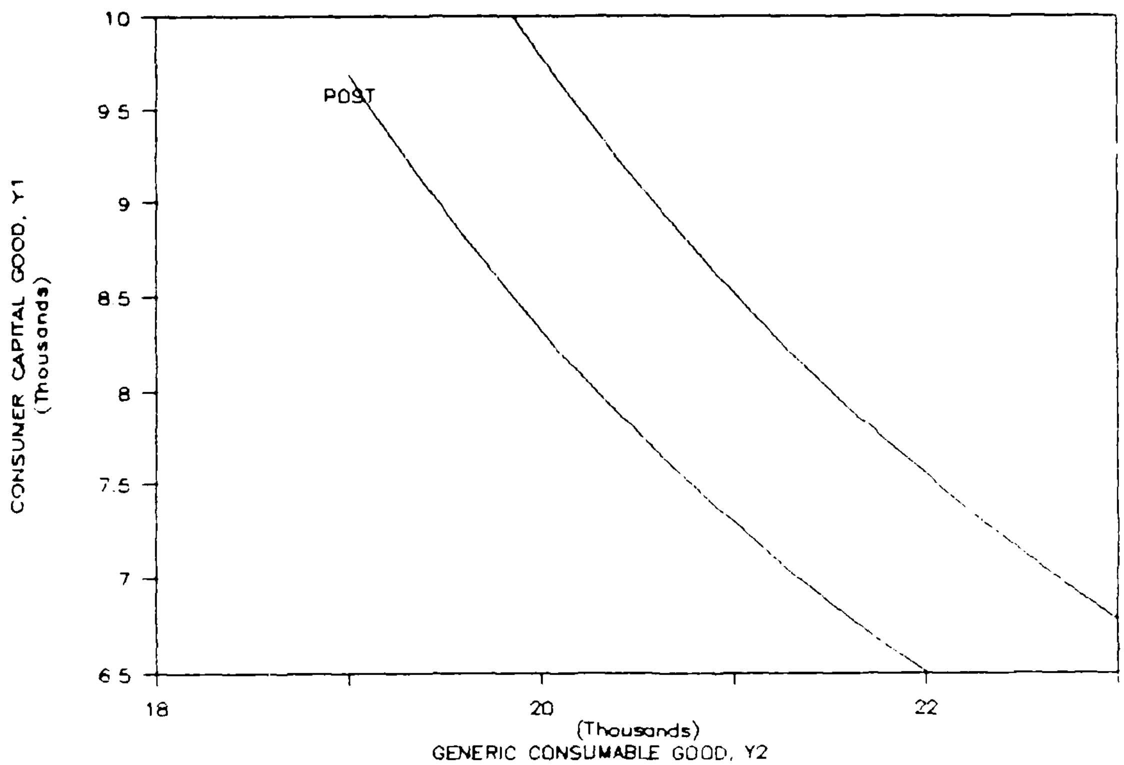
INDUSTRY 0 - Intermediate goods INDUSTRY 2 - Generic consumable
INDUSTRY 1 - Capital goods (construction) INDUSTRY 3 - Export

Wage rate = 180
Original rental price of capital = 57
Rental price of capital in the capital goods sector = 263

	Price	202	430	438	159				TOTAL	
	TO	0	1	2	3	CONS	GOV	EXPORT	PRODUCT	VALUE
FROM										
GOODS 0		0	0	21,303	0	0	0	0	21,303	42,979
GOODS 1		0	0	0	0	8,203	8,057	0	16,260	69,920
GOODS 2		0	0	0	0	21,303		0	21,303	93,356
GOODS 3		0	0	0	0	0	0	9,682	9,682	15,376
CAPITAL 0		0	0	0	0				0	0
CAPITAL 1		0	0	0	0				0	0
CAPITAL 2		0	0	0	0				0	0
CAPITAL 3		0	0	0	0				0	0
LABOR		11,939	12,396	21,095	3,885					
CAPITAL STOCK		38,012	18,105	21,948	14,827					
IMPORTS		0	0	0	0					
REVENUE		42,979	69,920	93,357	15,376			Gross		
COST		42,978	69,929	93,357	15,375			Regional		
PROFITS		0	-9	-1	1			Product		221,631
TOTAL OUTLAY		42,979	69,920	93,356	15,376					
								Value added		221,631

FIGURE A-4

LEVEL OF CONSUMER WELFARE: PRE- AND POSTDISASTER



equipment (fixed at 18,100 units) in place to create new producer and consumer capital is constrained. As a result, production of new investment capital can take place only by employing additional labor or by reducing the output of consumer products.[17] Given conventional production functions, this leads to a rising supply price of capital, which chokes off the process of reconstruction short of achieving the predisaster capital stock. The higher price of capital leads to an increase in both the price of consumables and residential construction, resulting in a decline in the region's welfare. In this instance it is not clear that compensation is equivalent to the value of damaged capital. A more thoughtful analysis is required.

Figures A-2, A-3, and A-4 depict the economy's path of recovery. Note that the increased price of consumables produces a situation where the higher priced imports become competitive. Note also that a portion of the undamaged capital stock is transferred from lower-valued activities (industry 2) to those which can afford to pay the quasi rents (industry 0).[18] In essence, industry 2 now performs a dual function. It is both a manufacturer and a capital broker, leasing or selling outright a portion of its own facilities. It retains capital for its own use, provided that its own value of marginal product exceeds the value of marginal product earned in the other sectors (which is the bid price). If it can't match the return elsewhere, it cuts production and markets the unused capital to the highest bidder. Unlike other general equilibrium models that have been developed this model accourts for quasi rents throughout the adjustment period.

A closer look at the model's underlying prices, outputs, and factor inputs proves the point. See Table A-7, the postdisaster trading pattern. As a result of the disaster, both wages and interest payments produced by the destroyed capital declines. But this is offset by increased rents and profits generated within the region due to the shortage of production facilities. Those fortunate enough to have been spared the effects of the disaster could sell or lease plant and equipment at a premium. From the standpoint of income, the economy appears to have recovered within the year. However, compensation is still required in order for households to purchase the goods and services essential in order to restore welfare. Prices, in terms of wage units, are shown to be higher throughout the rebuilding period. Hence, although nominal income remains unchanged, real income, deflated by the price changes, reduces the region's purchasing power. It is for this reason that compensation is required.

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[17]Recall that government demand is fixed throughout the process of reconstruction.

[18]This is due in part to the fact that industry 2 cannot produce without industry 0's input. When industry 0 is forced to cut production, industry 2 finds that an excess supply of capital exists.

TABLE A-7

POSTDISASTER STRUCTURE OF THE ECONOMY

Postdisaster rental price of capital 58

	Price	205	442	443	161				TOTAL	
	TO	0	1	2	3	CONS	GOV	EXPORT	PRODUCT	VALUE
FROM										
GOODS 0		0	0	19,935	0	0	0	0	19,935	40,787
GOODS 1		475	0	0	0	7,840	8,057	0	17,271	76,379
GOODS 2		0	0	0	0	20,839		0	19,935	88,258
GOODS 3		0	0	0	0	0	0	9,677	9,677	15,606
CAPITAL 0		0	0	0	0				0	0
CAPITAL 1		0	0	0	0				0	0
CAPITAL 2		1,696	0	0	0				1,696	98,605
CAPITAL 3		105	0	0	0				105	6,105
LABOR		11,330	12,667	19,831	3,915					
CAPITAL STOCK		32,800	18,105	20,251	14,721					
IMPORTS		0	0	0	0	899				
REVENUE		40,787	76,379	88,276	15,667			Gross		
COST		40,259	70,417	87,931	15,369			Regional		
PROFITS		52,790	5,963	32,753	23,732			Product		222,078
TOTAL OUTLAY		40,787	76,379	88,258	15,606					
								Value added		218,109

The Microeconomics of Adjustment

A more detailed analysis of individual consumer and producer decisions confirms and explains the adjustment paths discussed earlier. Figure A-5 shows the nature of the adjustment consumers are likely to face. Point A, as above, is the predisaster level of y1 and y2 consumed. The immediate effect of a dam failure is to reduce the availability of y0 to industry 2, which in turn must cut production. This reduces the amount y2 in the marketplace.

Assuming that relative prices of 1 and 2 have yet to change, the consumer faces a situation which is unsatisfactory; welfare (utility) could be enhanced by reducing demand for the relatively plentiful good (y1) and by substituting higher-priced imports (y2) for the once locally produced good. Recall that the capital used to create y1 is fixed, hence the only means for expanding its output is to employ additional labor (if the elasticity of substitution permits it). Investment to restore the destroyed capital can only proceed if the supply of y1 exceeds the sum of government and consumer demands. If this were to occur, the path of adjustment would proceed along path ABC. In the event that the price of the imported y2 is identical to that produced locally (i.e., its supply is infinitely elastic) then B might be the new permanent equilibrium.

Assuming that this is not the case, transfers sufficient to push welfare back to U_0 would produce the consumption combination shown at point D, meaning more y2 and less y1. The investment goods released to help restore the capital stock reduces the amount of compensation required in succeeding years, thereby pushing the consumption pattern along the path DA.

The microeconomics of industry behavior is equally instructive. The destruction of 15 percent of firm 0's capital leaves it with only 32,310 units just after the failure. A casual observer might conclude, erroneously, that 0 would have to cut its labor force 10,148, point B on the expansion path, Figure A-6. However, firm 2 possesses excess capital, since its fortunes are tied directly to 0's. Firm 2 would quickly discover that the rate of return it might earn leasing capital to 0 is greater than letting it lie idle. Hence, rather than moving up the expansion path BA, firm 0 would leap to point C and move up the adjusted path CA. The investment undertaken period by period expands the local supply of y2, which reduces its price relative to y1. Local production rises, replacing the more expensive imports. The process is complete once the predisaster level of production is reachieved (along with the initial capital-labor mix). Note that since wages are used as a numerare, the relative price of capital services to wage rates rises, thereby rotating the factor price ratio counterclockwise, thus permitting the substitution of relatively plentiful labor for scarce capital.

Figures A-7, A-8, and A-9 complete the picture. The immediate postdisaster decline in the production of y2 releases sorely needed capital to the highest bidder, which is firm 0. If this had not

FIGURE A-5

CONSUMER ADJUSTMENT TO THE DISASTER

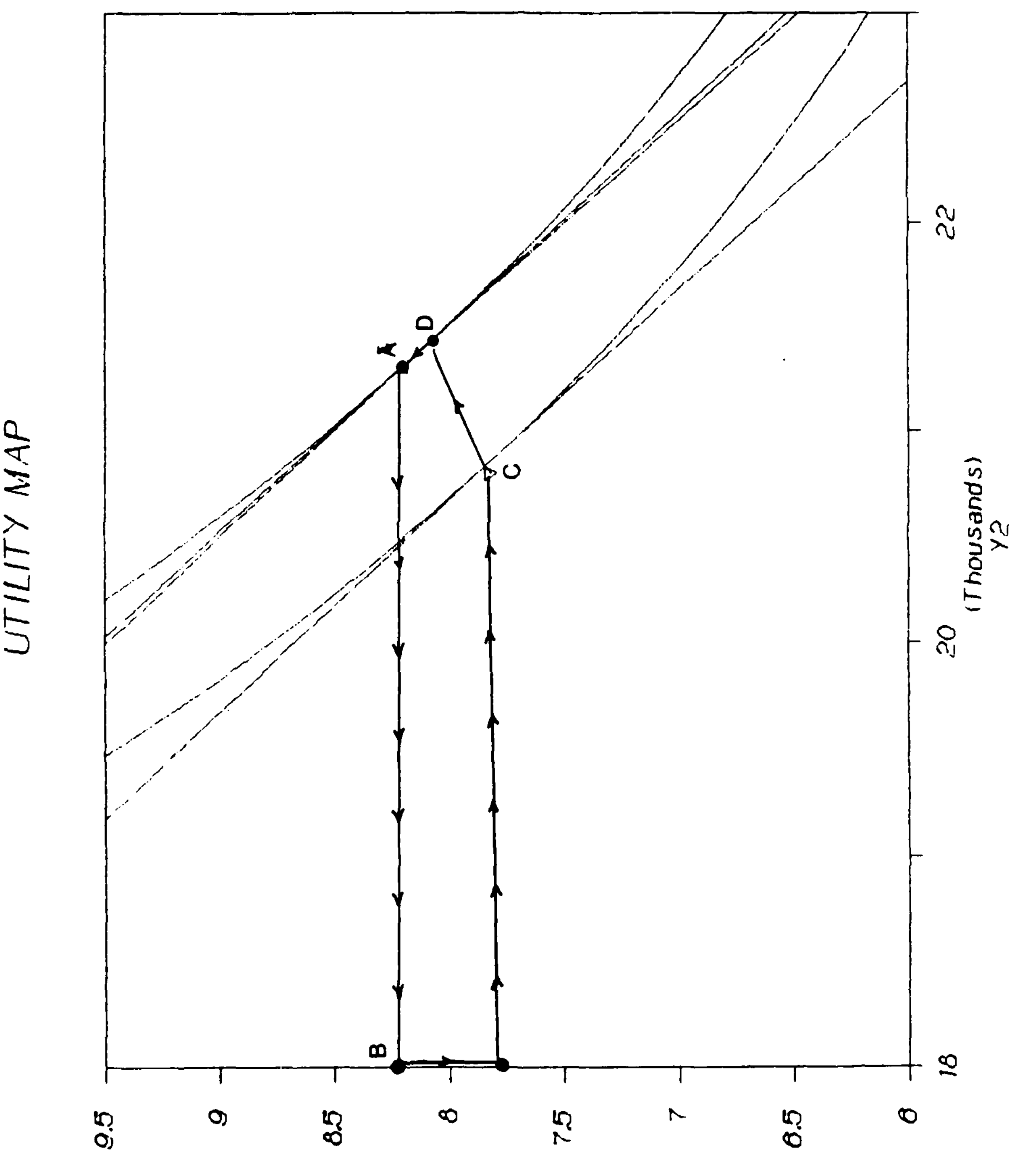


FIGURE A-6

ADJUSTMENT IN INDUSTRY O

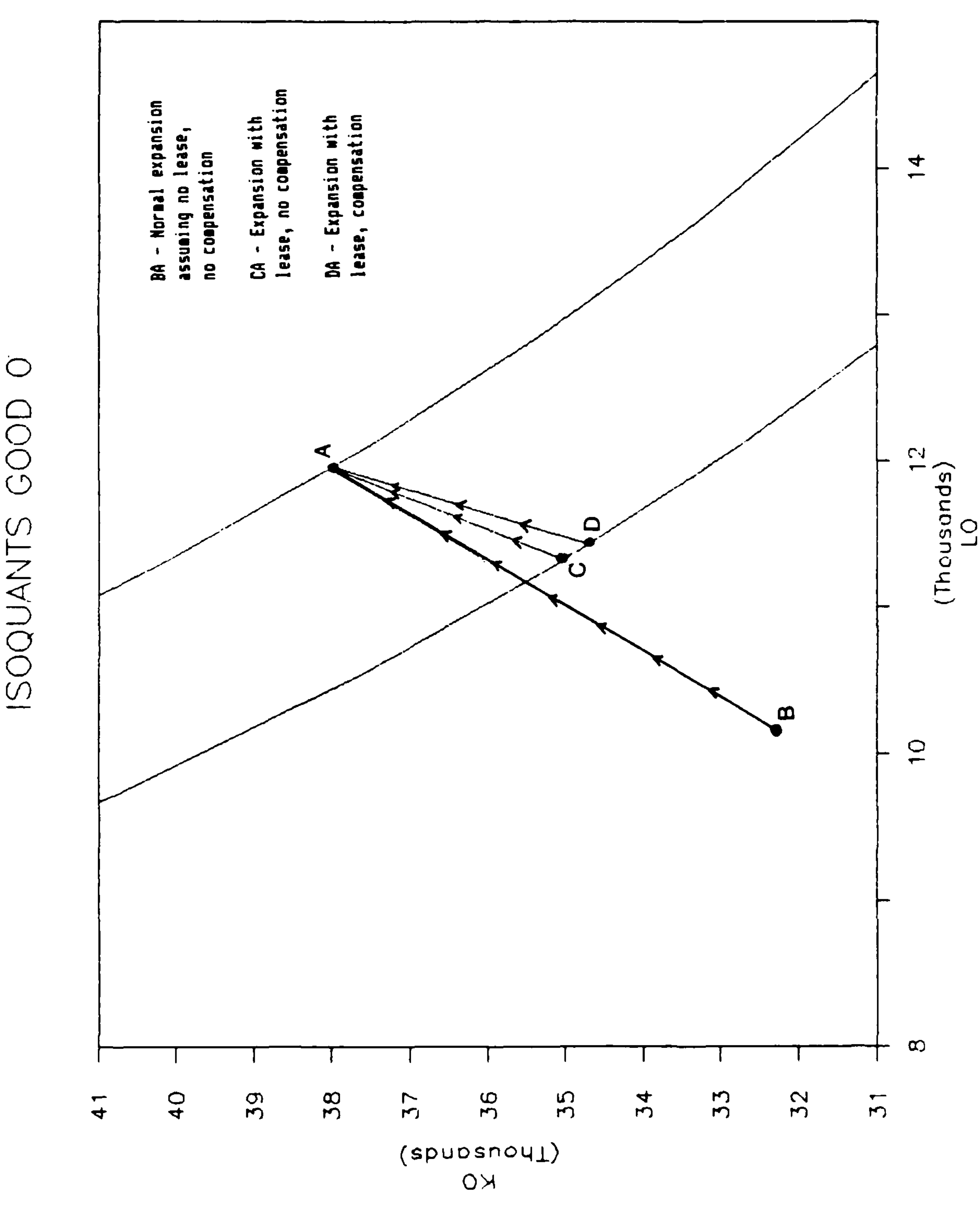


FIGURE A-7

ADJUSTMENT IN INDUSTRY 1

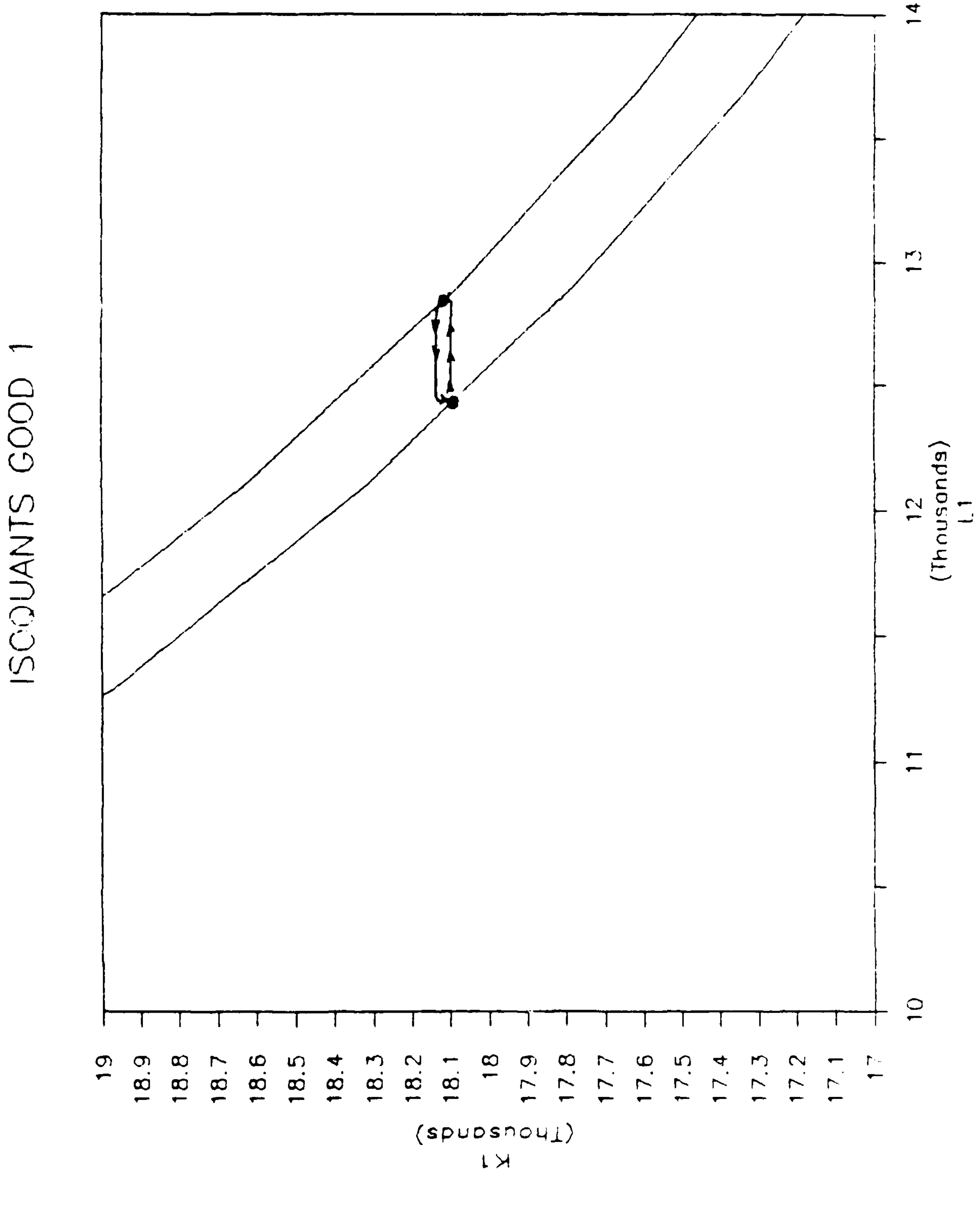


FIGURE A-8

ADJUSTMENT IN INDUSTRY 2

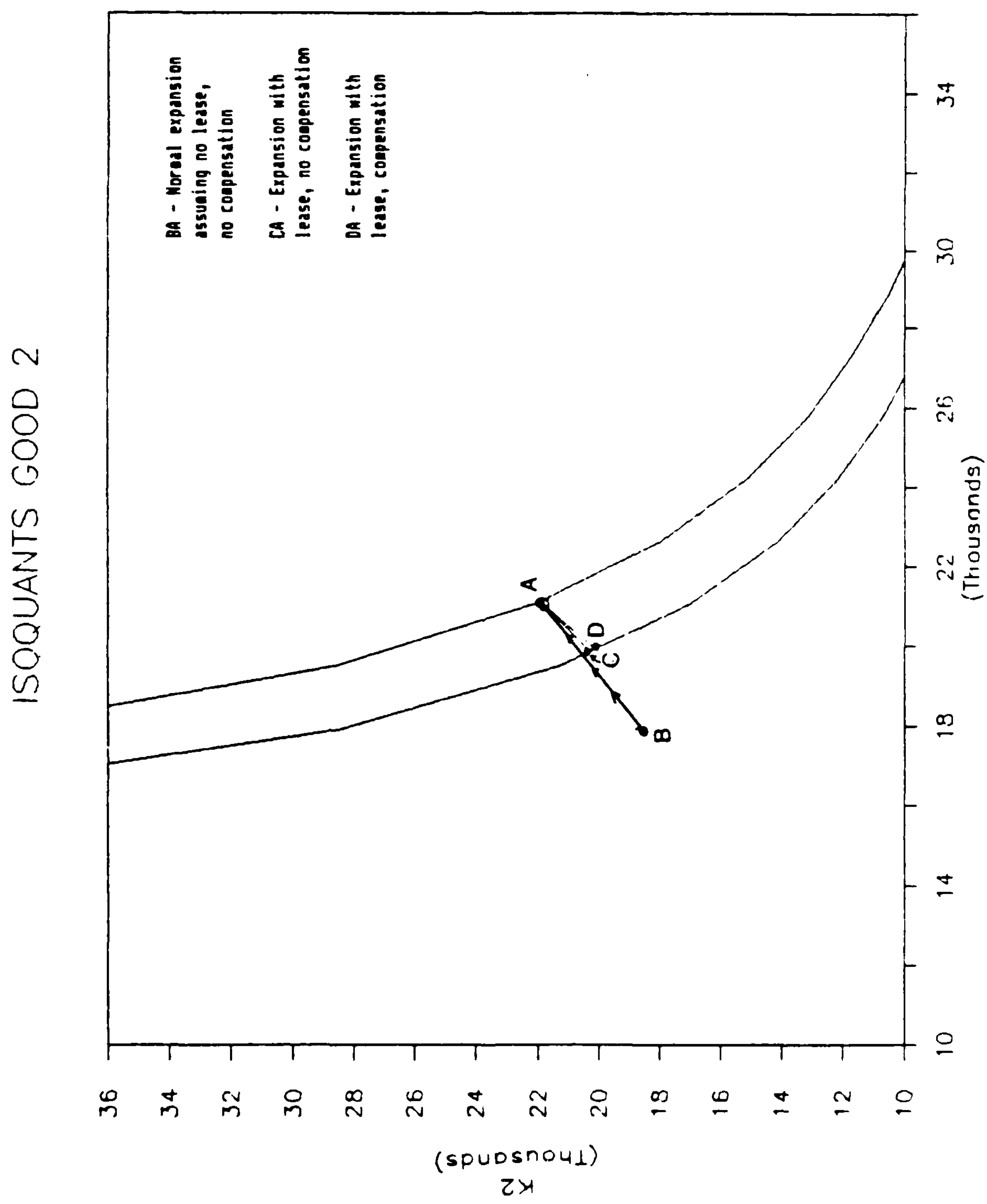
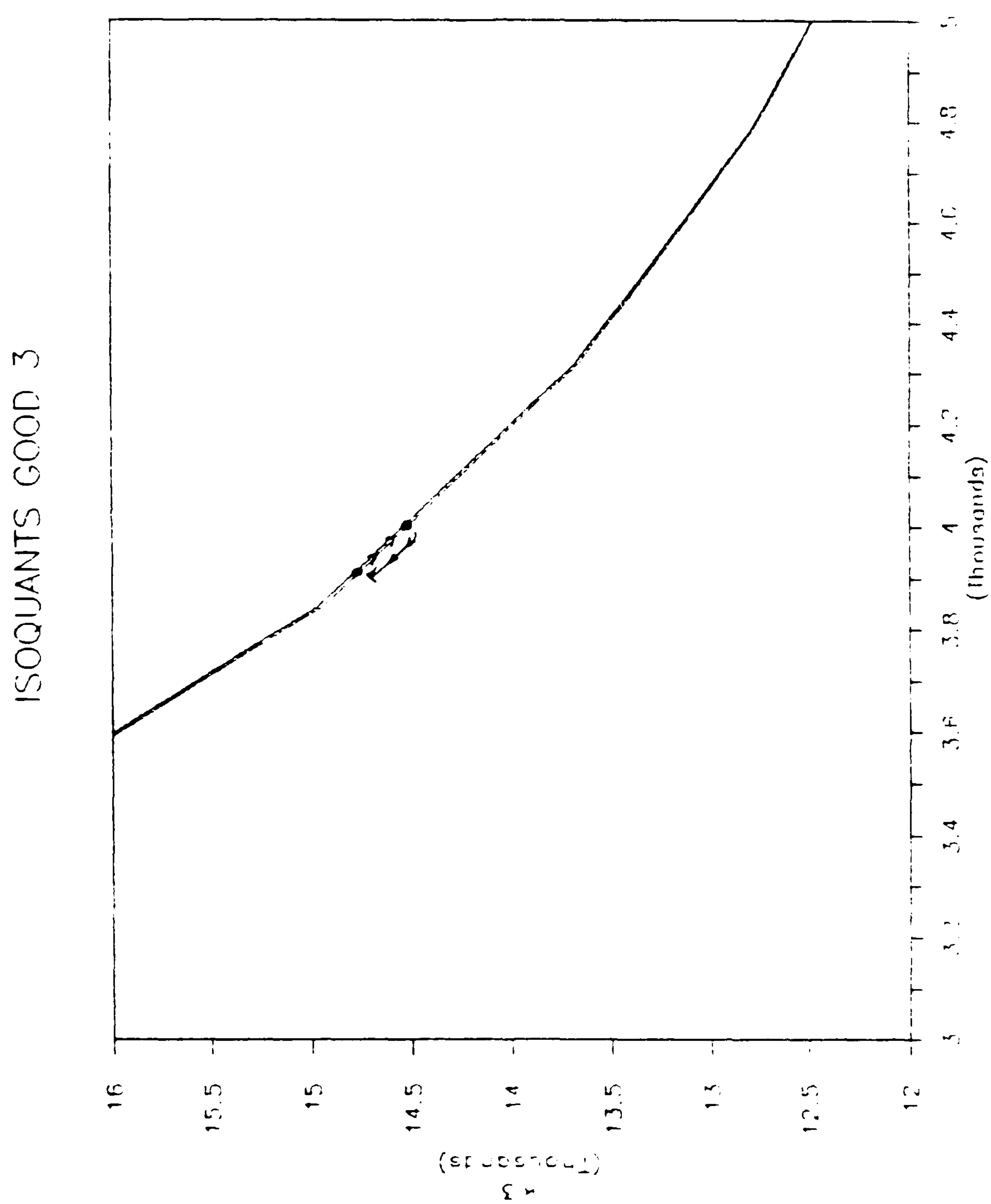


FIGURE A-9

ADJUSTMENT IN INDUSTRY 3



occurred, y2 would have dropped even further, to point B[19] in Figure A-7. The adjustment path for the capital goods industry (Figure A-8) is self-evident. The inability to expand its own capital base forces it to use additional labor to meet the needs of reconstruction. The level of employment in industry 1 begins at A, moves to B the period after the disaster, and then moves along path BC through the duration of the reconstruction phase. Figure A-9 shows that the production level for the export industry is little affected by the disaster. The reason for this lies in the highly inelastic demand for its products; hence, its own rate of return is too attractive to forego. As a result few units of industry 3's capital find their way to industry 0. This observation is confirmed by the results portrayed in Table A-7.

Experiments to Explore the Nature of Secondary Losses

A number of experiments were conducted utilizing the hypothetical case portrayed above. The following are just indicative of the wide variety of tests which could have been performed. Three were chosen to illustrate important aspects of the secondary loss issue.

The Effect of Paying Compensation on the Compensation Required

It was pointed out above that the actual payment of compensation, via a transfer from the federal to the local level, could exacerbate bottleneck costs. If so, the true measure of loss could be higher than first thought. To show the magnitude of this phenomenon, the general equilibrium model was exercised with two different assumptions regarding disaster payments. The first withheld payment. The period-specific utility levels were then recorded. These utilities were used to compute the compensation required to achieve predisaster welfare given that the price vector was assumed to be unresponsive to the transfers. The second incorporated payment, which resulted in a new price structure. The results of the experiment, normalized as a percent of the direct damages, are shown in Table A-8. The payment of compensation boosts the compensation required by a factor of 2. Note that this result is specific to the assumptions made regarding the production functions (elasticity of substitution) and import supply elasticity, among others. However, even so, the difference is remarkable. It appears that compensation can cause severe adjustment costs which must be accounted for. Failure to include the effects of compensation could introduce a significant bias into loss estimates.

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[19] In the absence of a capital transfer, firm 2 would be forced to cut production in direct proportion to the decline in firm 0's output. By leasing plant and equipment to 0, firm 2 earns rent (on the scarce capital). Even more important, the transfer permits 0 to expand its output, which has an obvious beneficial effect on 2's production.

TABLE A-8

THE EFFECT OF PAYING COMPENSATION ON THE COMPENSATION REQUIRED

The Effect of Paying Compensation on the Compensation Required	Ratio of True Measure of Loss to To Capital Destroyed
Not Paid	.96
Paid	1.82

Assumptions: Elastic import function (SL_{imp}=5,000) and high elasticity of factor substitution.

Elasticity of Import Supply

Table A-9 shows how the elasticity of import supply influences the true measure of loss, normalized by the value of the capital destroyed. Once again the difference in compensation required is quite sensitive, in this instance, to the competitiveness of the suppliers in other regions. The reason for this result is simple. Relatively inexpensive imports flow into the region to fulfill consumer requirements. As a result investment within the region lags, employment remains high throughout the adjustment period, and compensation must be paid not only to the owners of the destroyed capital but to unemployed laborers. To illustrate using an extreme case, if import prices and regional production costs were identical. compensation payments would be used to pay for imports. As a result of this leakage, the destroyed capital would never be replaced. This means that compensation would have to be paid each period in an amount equivalent to the principal and interest, or the dividend payments, that the owners of the destroyed capital would have received, plus the wage payments to the displaced laborers. In other words, value added would be permanently depressed by the value of the new imports. This discounted amount would be the true measure of loss. Since the region's relative prices would not change, the compensation is simply the income lost, the last term in equation (A15).

Table A-9 also shows another extreme and interesting possibility. In the event labor can substitute for capital, and import prices rise with demand (inelastic), the level of compensation could be less than the damage (the ratio shown is less than the value 1). It is clear that the additional employment reduces the need to provide federal transfers, so a reduction in annual compensation is not surprising. But, why is this amount less than the direct property losses? It must be that compensation (in the form of transfers plus the demand for additional investment) produces a multiplier effect which results in the observed phenomenon.

TABLE A-9

THE EFFECT OF PRICE ELASTICITY OF IMPORTS ON COMPENSATION

The Effect of Price Elasticity of Imports Compensation Required	Ratio of True Measure of Loss to Capital Destroyed
Inelastic	1.82
Elastic	.71

Assumptions: Elastic import function (SL_{imp}=5,000) inelastic import function (SL_{imp}=200), high elasticity of factor substitution, and compensation paid.

Elasticity of Substitution: Labor for Capital

Table A-10 illustrates the extent to which a firm's ability to substitute labor for capital influences the true measure of loss. Two sets of production functions were hypothesized, one more elastic than the other. See Table A-5, Production Functions. The numbers in parentheses are the elasticities of substitution. Note that the elastic set (designated ELAST.) exhibits values between .5 and 1. Using the value 1 to illustrate, a 1 percent increase in labor is required to compensate for a 1 percent drop in the availability of capital, if the rate of technical substitution is to remain unchanged. A more inelastic set of values (designated INELAST. in Table A-5) implies that labor is not easily substituted for capital. Slight changes in the capital-to-labor ratio produce significant impacts on productivity. At the extreme, the elasticity of substitution could be zero, implying a fixed relationship between capital and labor. No substitutions are possible.

As expected, the easier it is for firms to substitute labor for capital, the lower the level of compensation required. A low elasticity of substitution means that producer 0 cannot readily utilize labor to replace the capital lost in the disaster. This lack of flexibility translates into a level of unemployment which is greater than that which would have been observed had the elasticity been greater. It is this difference in endogenously generated employment which produces the difference in compensation observed in Table A-10.

TABLE A-10

THE EFFECT OF ELASTICITY OF SUBSTITUTION (L FOR K) ON COMPENSATION

The Effect of Elasticity of Substitution (L for K) on Compensation Required	Ratio of True Measure of Loss To Capital Destroyed
Inelastic	1.01
Elastic	.71

Assumptions: Inelastic import function (SL_{imp}=200) and compensation is paid.

The Effect of the Disaster on Income Multipliers

Table A-5 showed trade flows before and after the disaster. Note that the degree of interdependence is altered by the consumer and producer substitutions induced by the shock. The postdisaster flows imply new input-output technical coefficients and, subsequently, a change in income multipliers. Without going into great detail, the changes were negative, meaning that the disaster produced an effect which reduced the *ex post* multipliers. The reason for this is tied to interregional effects. Recall that the predisaster economic structure contained no import leakages. Hence, the *ex ante* Leontief inverse contained interactions which tended to overstate the effects of externally induced demand shifts (i.e., the payment of compensation). Shortages of y2 drew imports into the region, a phenomenon which could not have been anticipated by simply referring to the interindustry tables.

Summary

These quantitative results are, of course, less important than the methodology and the insights gained. The simulations do provide guidance as to the conditions which might lead to a significant discrepancy between private and social losses. It was already noted that the elasticity of demand for exports would influence the distribution of burden. I do not believe, however, that it will play a role in shaping the magnitude. The effect of disaster on a region's welfare can be traced to the following: (1) the elasticity of technical substitution observed in production; (2) the elasticity of substitution observed in consumption; (3) the marginal utility of income; (4) price differentials between regions; and (5) limited capital and labor mobility. The most important of these factors is capital mobility. It is not difficult to prove that, in the absence of adjustment costs (if replacement capital could be installed quickly at a cost equivalent to that of the damaged capital), the annual compensation and capital loss would be one and the same. Furthermore, it could be demonstrated that the form of aid to the region would not influence welfare. It should make no difference whether cash, physical capital, or consumer goods are provided; the effect in terms of compensation is the same.

These experiments resolve the double-counting question posed in the introductory section. It is clear that the treatment of employment and income effects independent of capital losses is incorrect. One is a measure of stock, the other is at least in part a flow from that stock. It is also incorrect to conclude that total losses are equivalent to the capital losses. This will only occur in the unlikely event that adjustment costs are zero. Once bottlenecks are introduced, capital and social losses will diverge, producing what has been commonly referred to as secondary effects.

APPENDIX B:

ANNOTATIONS

Baecher, Gregory; M. E. Pate; and R. Neuville. 1980. Risk of Dam Failure in Benefit-Cost Analysis. Water Resources Research 16(3):449-456.

According to Baecher et al. (1980), the failure of a dam will result in the following costs: damage to property downstream; income losses (in the event that damaged manufacturing operations and commercial activity cannot be carried on outside the region); emergency costs; and foregone benefits as a result of losing hydropower, irrigation storage, or control of flood flows. The sum of these costs adjusted by the probability of failure is the cost of risk which, according to Baecher et al., should be subtracted from project net benefits. Their analysis proceeds as follows.

The benefits received as a result of the dam's presence are assumed to be a constant (b) equal to the reduction in expected annual losses due to the controlled release of flood flows. If the dam does not fail, benefits b are received. If the dam does fail at time t* then flood losses would return to the level experienced prior to the time when the dam was first built. This loss of flood control benefits are assumed to continue from t* to T, the planned life of the structure. This last point is most puzzling. Reduced to the simplest terms it can only be interpreted to mean that if the dam fails, the population at risk, the number of residences, and the public capital in the floodplain would be identical to that which existed prior to the collapse.

Baecher et al. go on to solve for the discounted stream of foregone flood control benefits. Failure can occur at any time t* with the probability P(t*). The chance of failure is assumed to be equally probable each year throughout the planned life of the dam. The expected present value of foregone benefits is therefore P(t*) times the discounted benefit produced if the dam fails at t*. For example, if the dam fails at the beginning of year 1, all T year benefits would be lost. If failure occurs at the beginning of year 2, the benefit gained in year 1, b/(1+r) is subtracted from the total. If t* occurs at time T, the year the project ends, no losses are sustained.

Discounted Benefits Given Failure in Year t*

Lost benefit (failure in year 1)	$[(1 - (1+r)^{-T})/r] * b$
Lost benefit (failure in year 2)	$[(1 - (1+r)^{-T})/r] * b - b/(1+r)$
Lost benefit (failure in year 3)	$[(1 - (1+r)^{-T})/r] * b - [(1 - (1+r)^{-2})/r] * b$
Lost benefit (failure in year T)	0

The expected cost of the failure is therefore the sum of all losses times the probability of failure.

Baecher et al. do not note how flood control benefits would change if the failure destroys all property in the floodplain.

Bromet, Evelyn. 1980. Three Mile Island: Mental Health Findings. Pittsburgh: University of Pittsburg.

This report evaluates the mental health of three groups of residents--mothers of preschool children, nuclear power plant workers, and community mental health system clients--following the Three Mile Island (TMI) nuclear accident. Interviews were conducted at nine months and again at one year after the accident with the sample groups and with control groups living near another nuclear facility in Western Pennsylvania. The researchers collected data on sociodemographic variables, social support networks, current symptomatology, lifetime mental health, work stress, and overall stress variables.

Mothers of preschool children, particularly those living within five miles of TMI, were thought to have experienced additional stress as a result of an evacuation order issued to them after the accident and may have had concerns about potential radiation effects on their children. The sample was selected at random from newspaper birth announcements. Workers at TMI nuclear plant faced the greatest exposure to radiation as well as potential job loss. The sample was selected at random from union membership lists. Mental health system clients were theoretically the most vulnerable group in the study with a possibility that the stress of the accident may have increased their symptom levels. Additionally, some of the clients were believed to be chronically disabled and lacking the financial and mechanical means to leave the area at the height of the accident. The sample was randomly drawn from anonymous lists of adult mental health system clients treated during the six months prior to the accident, excluding those with retardation and organic brain syndrome. Control groups were drawn from the area in western Pennsylvania containing the Shippingport and Beaver Valley nuclear reactors. Financial constraints prohibited the inclusion of a second set of control groups from an area near a fossil-fuel power plant.

TMI mothers had an elevated risk of experiencing clinical episodes of anxiety and depression during the year after the accident. These clinical episodes were not associated with other stress and support factors but solely with the TMI site. TMI mothers also reported more symptoms of anxiety and depression at subclinical levels at both interviews than did Beaver County mothers. TMI mothers who were most symptomatic were those who had a prior psychiatric history before the accident, those who lived within five miles of the plant, and those with less adequate social support from their network of friends and relatives. Being pregnant at the time of the accident also was an important risk factor.

The rates of clinical disorder after the accident were higher for TMI workers than for Beaver County workers; however, rates were higher for TMI workers before the accident as well. Although rates were higher for TMI workers, the actual percentage differences were not very large. Subclinical symptom levels were similar in the two groups. TMI workers felt more rewarded by their jobs than did their Beaver County counterparts. In both areas, workers with greater social support were less symptomatic and felt more rewarded by their jobs.

More than h f of the mental health clients in both areas felt that TMI was danger and that living near a nuclear facility was safe. TMI clients w ceived the accident as dangerous and felt th living near a clear facility was unsafe had consistently higher anxiety scores. However, TMI clients did not show significantly higher symptom levels than Beaver County clients.

The President's Commission on the Accident at Three Mile Island issued a report stating that TMI produced ". . . immediate, short-lived mental distress." The results of the present study suggest that although this assumption may be true for some residents living near TMI, adverse mental health effects were seen in mothers as long as one year after the accident.

Bromet, Evelyn, and Leslie Dunn. 1981. Mental Health of Mothers Nine Months After the Three Mile Island Accident. <u>Urban and Social Change Review</u> 14:12-14.

The authors assess the mental health of recent mothers living near the Three Mile Island (TMI) nuclear plant and examine the relationship between the mothers' social support systems and their reported symptoms of depression and anxiety. Recent mothers were identified as a high risk group for three reasons: (1) mothers with preschool children living within five miles of the plant were the only group evacuated by the governor; (2) the President's Commission on TMI reported significant, acute psychological reactions among mothers living near the plant; and (3) British studies suggest that mothers of small children may have a higher rate of minor affective disorders than women without small children.

The sample was selected by reviewing birth announcements in area newspapers for the 15-month period prior to the accident and compiling a list of mothers living within five miles and five-ten miles of the plant. Mothers were interviewed in their homes nine months after the accident; a total of 314 provided complete information. Mental health professionals administered the interviews. Mental health was assessed in terms of both clinical and subclinical evidence of anxiety and depression using a variation of the Schedule for Affective Disorders and Schizophrenia, the Research Diagnostic Criteria, and the Symptom Checklist-90. Social support was evaluated using a structured interview schedule developed by the Psychiatric Epidemiology Program at Western Psychiatric Institute and Clinic. Stress was assessed by comparing the mental health of TMI mothers to that of mothers living near the less problematic Shippingport-Beaver Valley nuclear reactors and by analyzing the mental health of TMI mothers in relation to their perceptions of the incident. The median age of the mothers at both sites was 27-28 and most had one to two children. Several demographic variables were included in the study.

The rate of clinical episodes of depression and/or anxiety following the TMI accident was more than twice as high among the TMI area mothers than among the control group. TMI mothers had significantly higher scores on the depression and anxiety subscales of the Symptom Checklist than did the control group. Mean depression and anxiety scores for the TMI mothers were 0.47 and 0.37 respectively, compared to 0.32 and 0.25 for the control group. All scores were within the normal range for those scales. Four stress variables (distance from plant, evacuation, perception of TMI as dangerous, and the belief that living near a nuclear facility is unsafe); six social support variables (inner circle support, size, accessibility, confidant support, general support, and stability), and various demographic variables were analyzed. Although no true risk factors for clinical disorder were identified, variables were more predictive of subclinical symptoms with negative perceptions of the general network support factor being associated with higher levels of depression and anxiety. Manifestations of clinical levels of disorder occurred primarily in the two months following the accident while subclinical symptomatology levels were elevated as late as nine months after the accident. Results indicated that social support was strongly related to symptomatology and that perceptions of stress were less important than the actual experience. The authors conclude by recommending that programs be developed to address psychological effects of technological disasters.

Brown, G. W.; T. O. Harris; and J. Peto. 1973. Life Events and Psychiatric Disorders, Part Two: Nature of the Causal Link. Psychological Medicine 3:159-176.

This paper discusses methods for testing for and measuring the proportion involved in the causal link between life events and psychiatric disorders and the nature of the causal link. The study focuses upon schizophrenic and depressive patients.

The rate at which life events occur in relationship to psychiatric disorders may be considered in one of two ways: (1) the true rate, which is measured by random time sampling, and (2) the conditional rate, which is measured backwards in time from the onset of a disorder. A causal link is inferred if the conditional event rate is elevated in the period before onset, the causal period. At some point back in time the conditional rate should return to the true rate, which identifies the beginning of the causal period. In calculating the true patient event rate, the approach given here is to assume that a sample from the general population (matched for appropriate influential variables) experiences the same life-event rate as the patients, particularly for schizophrenic and depressive patients.

In the study of schizophrenics, the frequency of events in the patient group was similar to that of the control group for all three-week periods except for the three weeks immediately prior to onset, which suggests the strength of the causal link between events and onset. There was no indication that schizophrenic patients have an overall higher rate of life events although it is possible that the patient groups might have a somewhat elevated rate of life events, perhaps due to having poorer coping skills than the rest of the population. However, in some cases, especially with depressive patients, the rate of events in the patient group may not return to the community level during the study period, which indicated the presence of two types of causal period: short-term and long-term. This analysis is based on the assumption that certain individuals are potentially schizophrenic or depressive for genetic, constitutional, or other reasons and that onset can occur because of these or current environmental factors in varying degrees.

The nature of the causal effect may be regarded in two ways. The first emphasizes the importance of predispositional factors and downplays the influence of events that are seen as triggering an illness that would have occurred eventually. The second holds that events play an important formative role. Onset is either substantially advanced in time by the event or entirely caused by it. Triggering and formative effects are opposite ends of a continuum. This study refers to any onset not brought about by an observed event as spontaneous. The model contends that each individual has at any point in time a particular onset rate, or morbid risk probability, which is the probability that s/he will suffer an onset within a particular period of time. A life event may affect this onset rate for a limited amount of time or for an extended period. Thus, the assumption is that the effect of events is to insert independent (provoked) onsets into the ongoing (spontaneous) process.

Brought-forward time is the estimate of the average time from an onset produced by an event to the time when a spontaneous onset would have occurred had no events intervened. To estimate brought-forward time, some estimate must be obtained of the spontaneous onset rate near the time of observed onset. Brought-forward time is influenced by two factors. The greater the proportion of onsets preceded by an event and the rarer this class of events in the total community sample, the longer the brought-forward time. The length of the brought-forward time reveals the nature of the causal link. If it is long (i.e., twelve months or more), the supposition of a triggering effect is untenable. However, even if a triggering effect is indicated by a short index of brought-forward time it is also possible that a formative effect may have been involved, that the onset might never have occurred without the observed events. In the study of schizophrenic patients the causal period was determined to be three weeks, and the brought-forward time was estimated to be about ten weeks, which indicates a triggering effect. This does not, however, mean that other factors, such as environmental factors, did not play a part in the onset of schizophrenic symptoms.

In the depressive study an additional component was included; the severity of events was considered in addition to the rate of events. When all events were considered for both patients and control groups, the only clear result was an increase in the rate of events experienced by patients in the three-week period prior to onset, with a ten week brought-forward time, which suggests a triggering effect. However, when severity of events was considered it was revealed that markedly threatening events were rare in the comparison groups and relatively common in the patient groups, with a brought-forward time of two years, which suggests that such threatening events have a formative effect. Additionally, there was a fourfold increase in markedly threatening events throughout the entire year preceding onset, indicating a long-term effect for most of the events.

Buehler, Bob. 1975. Monetary Values of Life and Health. Journal of the Hydraulic Division, American Society of Civil Engineers 101:29-47.

This paper examines the next-of-kin and society-in-general concepts used in determining monetary valuations of human life. The measurement of human values is demonstrated by application to a hypothetical resort area endangered by floods for which flood control measures are being considered.

An examination of wrongful death legal actions revealed that the present worth of the lost lifestream of earnings is admissible evidence and perhaps the best support for securing an adequate award in court. For concerns regarding life and health, the use of human values is the best way to balance (1) different types of projects and programs and the disciplines that administer them; (2) separate parts of single projects; and (3) costs and expected returns and costs and residual risk. The value of an individual is his worth to this family in a next-of-kin concept and his worth to society in a broader concept. If a married father is killed, his worth equals the present worth of his lost lifestream of earnings. If a housewife is killed, her worth equals the present worth of the equivalent services of a maid and a governess. Children are miniature counterparts of their parents whose earnings or services are delayed until maturity. Their present worth is less due to rearing costs and a greater discounting period. These measurements apply to the society-in-general concept as well. Life and health values depend on age, training, occupation, marital status, and sex. To avoid the effort of evaluating individuals separately, a number of groupings can be assigned, a human worth evaluated for each group, and a weighted-average value determined for a typical individual group member.

A person's remaining stream of earnings depends on his/her probable lifespan. Life expectancy values are readily available. All age groups have the normal prospect of exceeding age 65, the most common retirement age; therefore, the stream of earnings will terminate before death. For the interval after retirement, an income equal to one-half that at age 65 is allowed because a retirement income usually consists of earnings deferred from an earlier period. Earnings must be estimated for the statistical population affected by a specific project or program by conducting census surveys or by interviewing public officials, clergy, and others knowledgeable of the demographic characteristics of an area. Earning trends which represent both earned promotions and periodic merit increases must be applied when computing human values. Length of experience, usually associated with age, is the best relating parameter. In the next-of-kin concept, only lost earnings in excess of subsistence costs (earned income providing the worker with necessities of life) may be used in calculating human worth. The society-in-general concept does not deduct subsistence costs. For children, all expenses of rearing until working age, adopted here as age 22, should be deducted from future earnings. In converting future earnings to present worth capital sums, the basic interest rate used for project analysis must be used in computing human worth values influenced by the project. Medical costs are legitimate additives to lost earnings in both the next-of-kin and society-in-general concepts. In the next-of-kin concept unconceived children do not affect human value; however, they are included under the society-in-general concept.

The society-in-general concept is likely to produce the highest values and is technically the most thoroughly supported. It is quite complex; if risks are to be appraised, it might be worth the additional complexities to secure the higher values of the society concept.

Twenty-six groupings are used for the resort city example, of which three are selected for demonstrations of human worth calculation. The next-of-kin concepts of human worth are applied. The three representative individuals are a 33-year old married man, a 33-year old housewife, and a 12-year old male child. For the man, the total present worth in case of death equals \$242,500. For the woman, the total present worth in case of death equals \$118,300 if childless and \$251,000 if there are children. For the child, the total present worth in case of death equals $148,700. For all 26 resort city groupings the composite human worth in case of death equals $166,000; the composite human worth in case of permanent disability equals $258,000.

The human values of the resort city example are compared with the results of other investigators; with actual court awards in cases of wrongful death; with amounts from miscellaneous sources having subjective or unidentified support; with the implied value of search and rescue costs following accidents; with costs willingly spent to prevent accidents; and with cost to kill an enemy.

Cochrane, Hal. 1986. A General Equilibrium Approach to Determining the Indirect Effects of Disaster. Working Paper, Department of Economics, Colorado State University.

The model is primarily intended to answer several questions important to the analysis of disasters.

Are disaster-induced employment effects, the so-called secondary losses, simply another measure of damage to productive capital?

Why have empirical studies failed to detect these secondary effects?

Should government postdisaster recovery plans be directed toward the maximization of regional employment?

Will better dissemination of probability information lead to an optimum level of protection, either in the form of contingent claims contracting or strengthening of vulnerable structures?

It should be noted that the model is primarily pedagogical. It is a highly simplified representation of a regional economy embedded in a larger system. The producer and consumer equations and interindustry trade flows are designed to be realistic and flexible yet manageable.

The size of the Disaster GEM was purposely limited in order to highlight the postdisaster adjustments triggered by a sudden shortage of consumer and producer capital. Four producing sectors are represented, each of which combines labor and capital according to a different CES production function. Two of the four sectors produce consumer items, however one of the two (best thought of as construction) also sells to other businesses and government. The remaining two sectors export items to other regions and produce an intermediate good utilized by the second consumer good industry (other than construction). The local government employs an income tax to generate revenues; its level of spending is exogenously given and is not tied to the occurrence of the disaster.

The economy's households are assumed to save a fixed proportion of their wage and interest income. The remainder is spent on the two consumer goods according to traditional utility-maximizing rules; preferences are represented by a Stone-Geary function. The price of goods which could be imported from other regions prior to the disaster exceeds locally manufactured items. Hence, under normal conditions there are no imports. However, since imports are assumed to be an increasing function of local prices, they may be observed after the disaster.

The sum of both direct and indirect losses stemming from such a disaster are determined by computing the compensation that must be paid the victims in order to restore the region's predisaster level of welfare (i.e., utility).

The effect of a hypothetical disaster was simulated utilizing the framework just described. The results can be succinctly summarized as follows:

> The compensation required to restore welfare can be less than, greater than, or equal to the value of the capital destroyed. It may take more than one time period for normalcy to return, in which case the cost of the disaster is the discounted stream of required compensation.
>
> If capital is perfectly mobile, disaster losses are identical to the value of capital destroyed. Damaged plant and equipment are instantaneously replaced at a cost equivalent to that prevailing prior to the disaster.
>
> If capital is not very mobile and imports are highly competitive (prices are equivalent) with regionally produced commodities, the damaged industry and other industries tied to it will never reopen. The losses in this case are the sum of direct damages, the cost of idle capital, and unemployed labor. In this instance compensation payments would be used to purchase lower priced imports. As a result the region's surviving capital stock would not earn rents (due to its scarcity) and there would be no reason to expand investment. The markets would be permanently lost.
>
> If capital is immobile, imports are more expensive then regionally produced goods and labor is easily substituted for the damaged capital, the discounted stream of <u>compensation</u> <u>is less than the value of capital destroyed</u>. This results from the combined effects of spending multipliers and the induced investment accelerator.

Cochrane, H.; J. Eugene Haas; and R. W. Kates. 1974. *Social Science Perspectives on the Coming San Francisco Earthquake--Economic Impact, Prediction and Reconstruction*. Natural Hazard Working Paper #25. Boulder: University of Colorado Institute of Behavioral Sciences.

The paper proposes a way of estimating the indirect losses from disasters. The technique is demonstrated using a simulated reoccurrence of the 1906 San Francisco Earthquake in 1974. It is argued that direct damage of productive capacity would retard the production of intermediate goods in the region. To the extent that serious shortages of critical goods develop and inventory levels are insufficient to absorb the effects of supply disruption before alternate supplies can be found, a further decline in regional output would be expected. It is this complex interaction of supply, demand, and damage which forms the basis of the analysis

Direct damages were estimated by overlaying previously published isoseismal patterns on a map of planning districts showing the relative concentrations of residences, the number of persons employed in basic industry, and the number employed in local service industry.

The resultant disturbance to the region's productive capacity was analyzed to determine how these effects filtered through other industries. Unemployment produced by supply constraints were translated into reduced demand for goods and services still produced in the region. The paper proposes that property and sales tax revenues would decline at a point in time when the need for expenditure is the greatest--when reconstruction of public facilities, roads, and utilities is vital to the recovery of the economic structure.

Several simplifying assumptions with regard to prices and production technology were employed, permitting the problem to be formulated within a linear programming framework. Regional product was maximized subject to the constraints imposed by the surviving resources and the pre-earthquake technical coefficients of production.

The paper points out the importance of focusing on value added rather than gross regional product in interpreting the results. The former is shown to decline by $14 billion while the latter is reduced by $6 billion. Regional product includes not only the value of economic activity of the region but also the value of goods and intermediate products made elsewhere. Value added reflects income to labor, capital, and other factors of production received within the region. It is therefore a more accurate reflection of the disruption an earthquake of magnitude 8.3 could produce.

In summary, Cochrane et al. conclude, "A repetition of the 1906 San Francisco earthquake would cost the Bay area a minimum of $13 billion, but the employment of more pessimistic assumptions than those used in this study may escalate the cost by a factor of three or four. These losses would be divided almost evenly between direct damage to personal, business, and public property (primary impact), and indirect damages in the form of a decline in regional economic activity (secondary impact)."

This study is one of the earliest attempts to derive an estimate of employment effects caused by natural disasters. Because of this the tools are crude and the results are primarily illustrative. A number of subsequent studies have been performed, some of which are included in the review. The primary criticism which can be leveled at the linear programming approach, which Cochrane et al. employ, is that the technical coefficients are unlikely to remain fixed during the period of reconstruction. In addition, rigidities in the economic system may preclude the rapid reallocation of resources as portrayed in such a model.

Covello, Vincent T., and Joshua Menkes. 1982. Issues in Risk Analysis. In Risk in the Technological Society, pp. 287-301. C. Hohenemeser and J. X. Kasperson, eds. Boulder, Colorado: Westview Press.

This paper outlines risk analysis issues warranting further investigation, which will be useful in the formulation of risk management policy. Five topics are outlined as future research needs:

(1) Risk assessments and their impact on risk management policies. Although risk assessments have been undertaken expending significant scientific and financial resources from both the public and private sectors, little attention has been given to the determination of the impacts of these assessments on risk management policies. Detailed institutional and organizational analyses could illuminate the processes necessary to translate assessments into social policy.

(2) Risk assessment and management at the regional, state, and local level. Many risks are managed at these nonfederal levels yet little is known about the risk management approaches used, existing risk management capabilities, and how regional, state, and local authorities vary in their implementation of federal risk regulations.

(3) International comparisons. With appropriate allowance for cultural and institutional differences, U.S. risk management policy could benefit from analyses of the experiences of other nations. Studies are needed to examine (a) the extent to which nations respond selectively to various technological risks; (b) the degree of consensus or disagreement in their evaluations of technological risks; (c) the interaction of risk management policies and social, economic, political, and

institutional factors; and (d) the effectiveness of alternative managerial strategies in reducing or mitigating risks.

(4) Public perception of risk. Relatively little is known about the cognitive processes that determine the perception of risk and the ordering of preferences by individuals. Studies are needed to examine (a) the psychological, social, and institutional factors affecting risk perception and choice; (b) the conditions or events under which risk perceptions and preferences remain stable or change; (c) how information about risk is communicated to and understood by decisionmakers and the lay public; and (d) the process by which individual perceptions of risk are aggregated and translated into social perceptions of risk and decisionmaking.

(5) Decisionmaking methods. Current methods have serious limitations--basic data are often inadequate, consequences of decisions are difficult to specify, it is difficult to incorporate equity and other normative considerations into decision models, there is no agreement on how to deal with uncertainty or value of life issues, and it is unclear how costs, benefits, and risks to future generations should be treated. Studies should examine (a) the extent to which decisionmaking methods have been used in risk management; (b) successes and failures in the applications of these methods; and (c) major unresolved methodological needs and prospects for resolving them in the near future.

The authors note that the increasing emphasis on government regulation of technological hazards raises several important problems. Laws and regulations are often inconsistent; government agencies often employ different approaches to risk management; it is difficult to design appropriate standards and regulations to govern the multitude of forms in which a hazard appears; in the event of violations, the magnitude of the response and adjudication process may overwhelm the resources of the regulatory agency; the economic costs of regulation may exceed the economic benefits; regulating a product or process may result in inequitable allocation of costs, risks, and benefits among various subpopulations; and, finally, an increased reliance on regulatory solutions may be less desirable than the provision of information to the public, personal good judgment, and after-the-fact claims for damages.

Dacy, Douglas C., and Howard Kunreuther. 1969. The Economics of Natural Disasters. New York: The Free Press.

The authors analyze economic behavior following natural disasters, present empirical evidence on short-term recuperation behavior, and examine capital and labor needs in disaster areas. Empirical illustrations of various economic behaviors following disaster are provided in case studies of communities following earthquakes, tornadoes, hurricanes, and flooding with a primary emphasis on the impacts of the Great Alaska earthquake of 1964. The primary objective is the formulation of a clear-cut case for the development of a comprehensive system of disaster insurance as an alternative to paternalistic federal policy.

Historically, the negative impacts of natural disasters have been related more to casualties than to property damage. However, as civilization has advanced, this life-property loss relationship has reversed. As the value of real property increases over time, it is to be expected that losses from natural disasters will rise although not at the same rate. Technological advancement in building materials and design, building-code regulation, damage-prevention projects, and increased information on hazardous areas are among the factors influencing a slower rate of growth in losses than in real property. Still, the potential for destruction is increasing steadily.

Most supply and demand problems facing a disaster area are short-run in nature because of aid forthcoming from outside regions. Even where shortages exist, unexpected patterns of supply and demand may develop. The concern of residents for others alters the demand for certain commodities and keeps prices lower than they would be under conditions of scarcity in a more normal, impersonal market situation. Food and housing shortages are avoided through the willingness of residents to utilize emergency stocks, refrain from hoarding, and offer lodgings to homeless friends and relatives. Realtors and store owners are hesitant to raise rents or prices during the recuperative period; in fact, selective reductions may be temporarily applied. Thus, the utility functions of disaster area residents are frequently altered during the short-run period. The price of a good will be highest if there is no sympathy between people in the community and no expectation of outside aid. If aid is anticipated, demand will be lessened and prices lowered. In the presence of altruism, prices of emergency goods may remain stable or even be reduced while consumers refrain from hoarding and increase available stock by utilizing stored goods.

In evaluating long-term recovery, which brings the community back to its predisaster economic level, it is important to distinguish between stock and flow effects. The catastrophe will damage physical and human resources and immediately reduce the stock of these factors of production. Over time, there will be a flow of resources in the form of capital (funds and equipment) and labor (migration behavior) that will affect the pattern of rebuilding activity. Long-term recovery appears to be a function of the type of capital damaged or destroyed. Inputs of labor and outside aid might be allocated during the initial emergency period to the public sector, then to the business sector, and finally to the residential sector so that commercial facilities might be expected to be rebuilt more rapidly than homes and apartments. At any given time, resources should be utilized in restoring the facilities whose contribution to overall productivity are the greatest. One way to increase the efficiency of disaster recovery is to devise a system of disaster relief that allocates resources to the various sectors of the economy at the appropriate moments of time. The speed of recovery will be determined primarily by the magnitude and type of outside aid to the stricken community. Recovery may be shortened if technological advances are applied to reconstruction activity. The crisis situation may actually encourage the adoption of such new technology which was previously available but not utilized.

The authors review the evolution of federal involvement in recovery activity following natural disasters. Many types of relief, such as technical assistance, materials, and essential services to stricken areas, are of significant benefit to the community yet have relatively low marginal costs to the government because of preexisting distribution facilities. Financial assistance is by far the most costly to the government. Many types of financial assistance are transfers, payments from one group of people to another which must eventually be paid for in full out of taxes. The savings to the federal government that would result from eliminating current forms of relief to the private sector could be used as a partial subsidy in a disaster insurance program. Specific criticisms against the current relief system include (1) the amount of aid to disaster victims depends upon federal classification of the area; (2) the federal policy frequently encourages economic actions that an individual would usually consider unsound under normal circumstances; and (3) federal relief does nothing to discourage individuals from moving into disaster-prone regions, thus perpetuating the need for future loans and grants. Suggested forms of insurance coverage include: (1) compulsory natural hazards insurance for all homeowners; (2) long-term comprehensive disaster insurance; and (3) issuance of separate natural disaster insurance, e.g., one policy for earthquake losses and another for water damage. A proposal is presented for including protection against floods, hurricanes, earthquakes, and other limited disasters under the extended coverage endorsement that normally accompanies fire insurance. The suggested system addresses economic criteria, marketability, and political factors.

Drabek, Thomas E., and John S. Stephenson, III. 1971. When Disaster Strikes. <u>Journal of Applied Social Psychology</u> 1(2):187-203.

This article describes family response patterns to a sudden evacuation in the face of flood waters. The responses of families who were geographically separated are compared to those of families who remained together, and implications for disaster planning are discussed. Interviews were conducted with evacuated families by trained interviewers with a branching, primarily precoded interview schedule in which questions were arranged to depict the chronological sequences in family behavior (warning questions followed by confirmation-effort questions followed by evacuation questions). Verbatim statements were used to check the reliability of the coding. Nearly all interviews were conducted within 6 to 12 months after the event. Usable interviews were obtained from 278 of the 360 families originally selected for interview.

On June 16, 1965, heavy rainfall resulted in a catastrophic flood of the South Platte River striking Denver, Colorado. There had been no major floods in this area for nearly 100 years. Approximately 3,700 people were evacuated from the Denver suburb of Littleton between the hours of 4:00-8:00 p.m. The notice to evacuate was issued by police cruisers and in a sporadic manner by radio and television stations. Most persons responded as family members rather than as isolated individuals. Many families (41 percent of those interviewed) were physically separated at the time of warning, but of the families together at the time of warning, 92 percent evacuated together. Family responses were strongly associated with the initial warning source and message content. Warnings were received directly from authorities (19 percent), through friends or relatives (28 percent), or via the mass media (52 percent). The content of the messages varied greatly, with warnings from authorities being perceived as orders to evacuate while warnings from the media and peers were perceived to be descriptive reports of the event rather than appeals to evacuate. The messages from various sources were, in fact, frequently the same. The misperceptions revealed the general process of interpreting warning information into a different context so as to reduce its threat potential.

Four evacuation processes emerged: (1) evacuation by default, in which individuals leaving the area to seek confirmation were prevented from returning; (2) evacuation by invitation, in which individuals were invited to join relatives elsewhere for the evening; (3) evacuation by compromise, in which family members agreed to evacuate in order to calm frightened individuals; and (4) evacuation by decision, in response to information about the threat. Over half of those interviewed did not think about how long they would be gone, and most of those who did assumed that they would return in a few hours. Nearly half selected homes of relatives as evacuation points, but over one-fourth simply went to higher ground overlooking the river. Behaviorally, few differences emerged between separated and intact families. There was a slightly greater tendency for separated families to seek message confirmation, which may have been a delaying tactic to allow family members time to unite. The absence of marked differences stems from the fact that many (64 percent) of the families originally separated were united before the actual evacuation and from the fact that few alternatives were available in view of later warnings perceived as "orders" to evacuate. In analyzing responses by women alone, women with children more frequently indicated initial thoughts of fear or anxiety than did women without children. The major factor influencing response was age of children; women with primary school aged children more frequently reported fear or anxiety. The major reaction reported by all parents was that their children were frightened and/or wanted to leave immediately upon receiving evacuation messages. Women alone with children old enough to discuss the event reported feeling more fear themselves. Thus, it was an interactional variable that proved most critical.

Several implications for community planning emerged. Planners must recognize that people respond not as individuals but as members of primary groups, with the nuclear family being especially important. Behaviors that traditionally have been discouraged by disaster response planners, such as telephoning friends and relatives, are very resistant to change and may be effective in relaying warnings and making evacuation arrangements. Warning messages from friends and relatives were three times more effective in producing adaptive behavior than were media messages, with telephone conversations being a key factor. It might be more effective to include such behavior as planning resources than to attempt to discourage it.

False expectations that the public will panic, which have been consistently disproved in the disaster response literature, frequently produce adverse effects. Actions based upon this expectation may precipitate new community definitions of disaster that could critically affect future response. For example, a community that has been rushed from a threatened area without adequate information or the opportunity to make decisions about personal property may decide to delay future responses based upon their perception of the witholding of information by public officials. Officials should focus on concerns more critical than looting, which is much less of a problem than officials believe it to be. Planners should establish mechanisms for rumor control and message consistency. A better system of alerting the public should be devised. For example, automatic messages relayed through the telephone system may be more effective than sirens in areas where disasters are infrequent. Disaster plans should be based on empirical research that illustrates how people tend to behave in such situations. Planners should first consider the disaster as it is defined by family members and then shift back to their own global perceptions.

Erikson, Kai T. 1976. Loss of Community at Buffalo Creek. American Journal of Psychiatry 133:302-305.

The author reviews the emotional consequences of the destruction of a community as revealed by the survivors of the Buffalo Creek flood disaster.

Survivors of the Buffalo Creek flood sustained two types of trauma, an individual trauma and a collective trauma. Individual trauma is defined as a blow to the psyche that breaks through one's defenses so suddenly and with such force that one cannot respond effectively. Collective trauma is defined as a blow to the tissues of social life that damages the bonds linking people together and impairs the prevailing sense of communality. The two are closely related, but either can occur in the absence of the other.

Three psychosocial effects of the Buffalo Creek disaster are discussed: demoralization, disorientation, and loss of connection. Demoralization was evidenced by a lack of personal morale, expressed as apathy, and by a deterioration of moral standards among the displaced survivors, although the survivors perceived the collapse of morality to be more extensive than evidence would suggest. The author notes that certain forms of deviation were actually on the increase but that the breakdown of accustomed neighborhood patterns and the displacement of people into unfamiliar refugee groupings had increased the level of suspicion people felt toward one another. Disorientation among survivors of disaster is a common effect, but it persisted to an unusual degree among the Buffalo Creek survivors. Feelings of alienation and dislocation were common, as were behavioral manifestations such as forgetting simple pieces of information (e.g., their own telephone numbers, the names of close friends); the inability to locate themselves spatially (failure to recognize familiar landmarks); and the tendency to answer factual questions about time as if history had stopped on the date of the disaster. A loss of connection, or a sense of separation from others, was nearly universal among the survivors. Both the sense of self and relationships with others had been formed and maintained by the community. Without the community upon which they had depended, survivors could not sustain a sense of self, nor could they summon the energy to respond to other people. Human relationships had been defined by the customs of the neighborhood, the ways of the community, and the traditions of the family, and not by individual skills.

Haimes, Yacov, and W. Hall. 1974. Multiobjectives in Water Resources Analysis: The Surrogate Worth Tradeoff Method. Water Resources Research 10(4):615-623.

The Haimes and Hall approach to multiobjective optimization borrows the principles of consumer theory. First, they identify the attributes of the decision problem, safety, recreational values, economic efficiency, environmental protection, etc. Next they determine a set of noninferior solutions, that is, combinations of attributes which are most efficient in a Pareto sense. More than one attribute could not be obtained without giving up some of another. Such a procedure produces a set of shadow prices for each objective (which is also a constraint for all other objectives). Once a Pareto solution has been achieved, the worth of any one objective can be evaluated in terms of a trade-off; how much of one must be sacrificed to boost the achievement of another.

Their approach could incorporate a risk-efficiency trade-off (the value of the Lagrangian multipliers). The slope of the resultant noninferior set provides the public decision maker the information to make trade-offs, hopefully reflecting the preferences and values of the individuals he/she represents. Given a two-dimensional problem, such as that just posed, the shadow price of safety can be measured in dollars since efficiency is the companion objective which must be sacrificed. According to this paper the optimum mix of objectives is one which reflects social preferences and values. To the extent that the public agent fully understands the information presented and is able accurately interpret the community's values, the optimum solution can be achieved. This is done by simply asking the public agent to make the necessary trade-offs in light of given information about the noninferior set.

Ikle, Fred Charles. 1958. The Social Impact of Bomb Destruction. Norman, Oklahoma: University of Oklahoma Press.

This book estimates the sociological and demographic impacts of widespread bomb destruction and relates the physical effects of nuclear destruction to their social consequences.

Mankind's actual experience with nuclear bombings of cities is limited to the explosions at Hiroshima and Nagasaki. The only empirical evidence with which to examine the effects of nuclear bombings comes from those cities, yet those exposions resulted from single atomic weapons far smaller than those stockpiled today. Substitutions for missing evidence may be attempted through the examination of the effects of physical damage of other wartime and peacetime disasters on social and economic phenomena and through the use of data from natural disasters and World War II bombings to discover how social effects change with varying degrees of destruction. However, the possibility exists that entirely new social or psychological factors may result from destruction as extensive as that likely to accompany nuclear attacks.

In order to examine the physical and social impacts of bomb destruction, the author portrays the city as a complex of interrelated physical and social functions that may be represented by separation into functionally homogenous relationships which consist of two components: resources and consumers. The consumer-resource ratio reveals the relationship between the two. This ratio is elastic with respect to destruction and disruption. The degree of elasticity is determined by (1) pre-destruction consumer density (or resources scarcity), (2) divisibility of resources or consumption, and (3) organizational problems. Also important is the concept of disproportionality of effects from increasing destruction. After physical destruction exceeds a certain percentage of the city's total resources, further increases in destruction will result in disproportionately greater increases in social effects. The phenomena of elasticity and disproportionality apply not only to cities but also to regions or to an entire country.

In assessing the consequences of casualties resulting from a disaster, the author notes that the effect of casualties upon the functioning of the remaining labor force and upon socioeconomic life is not homogenous but one of four principal types: (1) the direct manpower loss; (2) the indirect manpower loss as workers are displaced into caring for casualties; (3) disorganization due to casualties among business leaders or important officials; and (4) the effect upon general "morale," where experiencing casualties or the risk of future casualties will affect the emotions and motivations of the survivors and might consequently influence their behavior.

Linnerooth, J. 1979. Value of Human Life: A Review of the Models. Economic Inquiry 17:52-74.

This paper addresses the value of life and safety. Linnerooth reviews the traditional models proposed by economists. The argument proceeds as follows. A utility-maximizing individual should be willing to entertain a potential trade-off, wealth for safety. Let Po be the probability of failure. The expected utility received from consumption over the individual's life cycle would be

$$E(Ul) = Po\ U(C)$$

U(C) is the utility derived from consumption. The total differential of this expression is

$$d[E(Ul)] = U(C)\ dP + Po\ U^1(C)$$

$U^1(C)$ is the marginal utility of an additional unit of consumption. The righthand side of the equation is comprised of two terms, the amount of expected lifetime utility would change due to a shift in the probability of survival (leftmost) and due to income spent on consumption (rightmost). Setting the change in expected utility equal to zero and rearranging terms, we see that the willingness to trade off safety and wealth (i.e., discounted income) is nonlinear.

$$dC/dP = U(C)/[Po\ U^1(C)]$$

Given that the individual in question is concerned for himself alone and does not save, consumption must be equivalent to income and subsequently to wealth. Several important observations can be made with reference to the trade-off implied by this model. First, the spotlight is on the individual's willingness to pay to improve safety.

The value of a statistical life is embedded in this valuation but it is not the central issue. Second, the shape of the function resolves a paradox, that is, although the individual places an infinite value on his/her own life, he/she is willing to accept compensation for incurring additional risk. As a direct result, the higher the chances of survival, the lower the value attached to additional safety. For example, an individual might pay $100 to purchase a smoke detector which reduces the probability of perishing in a fire from .001 to .002. However, this same individual would be willing to pay less than $100 to reduce the probability of death from .007 to .008. Third, the framework provides a rationale for conducting empirical studies of risk. Theoretically, willingness to spend on life-prolonging measures such as smoke alarms and homes in unpolluted neighborhoods should be observable, as are wage rate differentials for occupations exposing workers to different degrees of risk. Even government expenditures on hazard reduction reflect how the political sphere has internalized such trade-offs. Fourth, the use of willingness to pay is consistent with the requirements of BCA; it focuses attention the choice process which could enhance welfare (lead to a Pareto improvement). Fifth, it provides a pecuniary index of safety which can be combined with other monetary measures such as damage, lost income, etc. Sixth, willingness to trade off safety for wealth is a function of age and income and most important perception of risk.

Mark, R. K., and D. E. Stuart-Alexander. 1977. Disasters as a Necessary Part of Benefit-Cost Analyses. Science 197:1160-1162.

This article emphasizes the need to include low-probability events such as dam failures, impoundment-induced earthquakes, and landslides in the benefit-cost analysis of reservoir projects. It is not concerned with actual methods of estimation although examples are given of the methods discussed.

Benefit-cost analyses for water projects generally have not included the probable value of the costs of low-probability events. The significance of expected costs is reflected in the growing difficulty of obtaining liability insurance against dam failure even at highly inflated prices. Dam failures are not uncommon; failures have generally resulted from design, construction, or site indadequacies, or from natural phenomena, primarily storms or earthquakes. Generalized estimates of dam failure probabilities can be based on historical frequency observations, either aggregated or, if sample size permits, disaggregated into categories and time periods. From 1959 to 1965 worldwide failure rates have been estimated to be approximately 2×10^{-4} per dam-year while failure rates in the United States since the 1940's have been between 1×10^{-4} and 2×10^{-4} per dam-year. Historical trends may result from the balance between improving technology and the need to use more difficult dam sites. Project-specific probabilities of failure can be estimated by "fault tree" analysis of the probabilities of causal events such as major earthquakes, floods, and other failure mechanisms. The failure probability for some dams may approach the probability of severe local earthquakes. A consensus that some of the dams in any seismic region would fail if shaken by the maximum possible earthquake for that area has been reported. The probability of failure of a particular dam is difficult to estimate but may depend on many factors, including project-specific engineering and construction, geologic setting, surface faulting and seismicity, type and age of dam, and flood frequency.

In addition to failure probabilities, expected costs must also include estimates of the failure-related damage. Methods of calculation for such estimates are related to routinely calculated flood control benefits. Damage will depend on such factors as storage volume, topography, cause and mode of failure, and location, density, and type of existing and projected development. The expected cost of an event is its probability of occurrence times the cost of the damage. To calculate an expected annual cost of dam failure for a specific project, it is necessary to multiply the probability of each important failure mode by the estimated associated damage and then sum over the failure modes.

Impoundment-induced seismicity has occurred in both seismically active and inactive regions. Earthquakes triggered by the impoundment of water have damaged two dams and caused damage to many other structures as well as loss of life. No dams are known to have failed from impoundment-induced seismicity, but such earthquakes contribute to the probability of dam failures. More than 40 reservoirs reportedly have triggered earthquakes ranging from microseisms to (about) magnitude 6.4. Many of these cases are well-documented; others are inconclusive or questionable. There is a positive relationship between water depth and the observed frequency of reservoirs associated with earthquakes for all cases of significant (magnitude 3) induced seismicity. Although the a priori probabilities of impoundment-induced seismicity are significant for deep reservoirs, for a specific site the probabilities depend strongly on geologic and tectonic setting. In addition to the damage associated with dam failure, consideration must be given to direct seismic damage to man-made structures, which depends on density and type of development, was well as the geologic setting and earthquake magnitude. Many estimates of earthquake damage in the United States should be directly applicable to induced earthquakes. An example of other low-probability events that can also cause disasters is the landslide-induced flood associated with Vaiont Dam in Italy that killed more than 2,000 people in 1963. The landslide generated a giant wave that overtopped the dam and flooded the valley below (the dam did not fail).

When projects are designed, tradeoffs are made between project cost and residual risk. The expected costs of low-probability disasters associated with water projects can be significant and should be specifically estimated for each project. "High risk" projects could have appreciably higher failure rates than the mean probabilities of $1\text{-}2 \times 10^{-4}$ per dam-year mentioned previously. Even without the consideration the value of lives lost, the total expected damage due to dam failure, particularly in urbanized areas, can be so great as to exceed project benefits. The failure to include these costs of residual risk in benefit-cost analyses produces an upward bias that may result in projects that are not economically justifiable.

Mileti, Dennis S. 1975. Natural Hazard Warning Systems in the United States: A Research Assessment. Boulder: Institute of Behavioral Science, University of Colorado.

The author reviews the basic structures of integrated hazard warning systems, assesses the capabilities of existing warning systems for various natural hazards, and explores oportunities for future research efforts.

Cross-hazard warning research is closely related to hazard-specific warning research. Basic warning system processes may be conceptually the same although different hazards possess different physical characteristics which may affect warning system requirements. An integrated warning system incorporates three basic processes: (1) evaluation--the detection, measurement, collation, and interpretation of threat data (prediction and forecast processes); (2) dissemination--the decision to warn, and message formulation when warning is not accomplished by purely technical means; and (3) response--by those who receive the warning. Hazard warning capabilities involve certain basic components: observation systems, interorganizational communication systems, forecasting centers, and public warning-dissemination systems. Among existing warning activities the components vary in level of adequacy; public warning-dissemination systems currently are the least adequate.

Past experience, perceived negative public reaction, and perceived impact probability are known to affect how and if warnings are eventually disseminated to the public. Past research efforts have revealed three important concepts regarding human response to warnings: (1) even though several persons may listen to the same warning message there may be considerable variation in what they hear and believe; (2) people respond to warnings on the basis of how what they hear stimulates them to behave; and (3) people are stimulated differently depending on who they are, who they are with, and who and what they see. There is evidence that some portion of a population will fail to take appropriate protective action regardless of warnings. Certain stipulations apply for any message from a warning system: (1) if the message or signal is received at the local level without alteration, it must be received promptly and contain clear, concise information which can be easily and quickly understood by the local individual, whether official or other resident; (2) if the local recipient successfully disseminates the information to all relevant local persons, the message must be received promptly and must contain information necessary for residents to make rapid, rational decisions about appropriate actions; and (3) if the local resident interprets the message correctly, he must know the appropriate action to take and be motivated to act in time. To be appropriate, action should prevent loss of life and injury, minimize property damage, and there should be a "safe area" that can be reached in time.

Two types of constraints exist for integrated warning systems: those which inhibit the development and adoption of such systems at local levels, and those which reduce the effectiveness of warning systems when in operation. The adoption and maintenance of warning systems may be influenced by such factors as hazard repetition, community officials' awareness, and legislated requirements at the local level. The effectiveness of systems may be affected by technical problems in accurate assessment and prediction of the event and in distributing information to public warning disseminators; by inadequate community preparedness or organization; or by community disseminators not knowing how and what information should be dispersed to the public in light of the various factors which affect an individual's response to hazard warnings. Thus, two types of knowledge are important to any warning system: technological knowledge for hazard forecasting, and social scientific knowledge for the structure and operation of the system.

Future research efforts should address (1) the social and psychological factors which affect warning response; (2) the links among the groups and agencies which evaluate threat information and disseminate public warnings; (3) warning content and modes of communication; and (4) means to secure the adoption and maintenance of integrated warning systems in adequate preparedness programs. The author stresses that no significant benefit will be attained from research on any component of warning systems unless what is currently known and what is discovered is put to use in specific communities for preparing for specific events.

Newman, C. Janet. 1976. Children of Disaster: Clinical Observations at Buffalo Creek. American Journal of Psychiatry 133:306-312.

The author reviews the results of the psychiatric evaluations of several children who survived the Buffalo Creek flood disaster. The paper focuses on 11 children, all under the age of 12, selected from the group of 224 children evaluated. The evaluation procedure began with an interview of the entire family with individual interviews following. Outlines of each child's developmental history and pre- and postdisaster functioning were obtained from interviews of mothers. Interviews of the children included past and present family life, personal feelings, school experiences, and the children's perceptions of future hopes, the nature of the disaster, and the meaning of the lawsuit initiated by the survivors. Fantasy-eliciting techniques used included "three wishes," "draw a person," and story telling.

The impacts of the flood disaster on children can be attributed to three factors: (1) their developmental level at the time of the disaster, (2) their perceptions of the family's reactions to the flood, and (3) their direct exposures to the disaster. The children's drawings of the flood event indicated a variety of serious developmental interferences and distortions in their cognition of human body images. Exposure to chronically anxious parents or, as in the case of children in utero at the time of the flood, exposure to familial stresses resulting from an event they never witnessed will cause children to be more affected by their family than by the disaster itself. Direct exposures to the flood may include exposures to the dead and dying, to the destruction of homes and possessions, and to the sight of human suffering and helplessness against the forces of nature. The symptoms produced in the children of Buffalo Creek include insecurity, extreme attachment to and reliance upon parents, fear of water, bedwetting, nightmares, behavior disorders, personality changes, deteriorating academic performances, and somnambulism.

The author concludes that children form their own theories of disaster based on their own reactions, their perceptions of the reactions of their parents and other adults, and the social and legal processes that follow disasters. These factors continue to affect them as they grow; common consequences of disaster for children include a modified sense of reality, increased vulnerability to future stresses, an altered sense of powers within the self, and a precocious awareness of fragmentation and death.

Okrent, David. 1982. Comment on Societal Risk. In Risk in the Technological Society, pp. 203-215. C. Hohenemeser and J. X. Kasperson, eds. Boulder, Colorado: Westview Press.

This paper addresses the difficulty of defining and quantifying risk in human society.

Society is not, nor can it be, risk free. Specific observations regarding risk in this society are (1) There are large gaps in society's understanding of risks and the economics of risk management. Risk-benefit analysis should be employed as an important decision-making tool. (2) The consequences of two different hazards may vary greatly with respect to their measurability. Although some hazards present risks that are difficult to quantify, for many societal hazards risk quantification is possible and desirable. (3) Society uses the word "safe" in a vague and inconsistent fashion. (4) In view of their statistically smaller contribution to societal risk, major accidents may be receiving proportionately too much emphasis compared to other sources of risk. (5) Society's resources are limited. Above a particular level, expenditure of resources on additional programs to reduce risks to health and safety may be counterproductive due to adverse economic and political effects. (6) Congress should take the lead in establishing a national risk management program that is equitable and more quantitative.

Published assessments of the many hazards and risks to which society is exposed are scarce. For example, it is difficult to find published quantitative estimates of the risks posed by the thousands of large dams in the United States. The safety of such dams is generally poorly known, particularly in terms of the more serious, lower probability modes of failure. Historically, large dams have failed at a rate of about 1 in 5,000 per year, although estimations of the failure rate for some dams may be as large as 1 in 100 per year. The state of California has had a dam-safety law since the 1971 San Fernando Valley earthquake specifying that the safety of each state-controlled dam must be reviewed and determined to be "safe." However, the state need not publicize the risk it is imposing when it determines that a dam is safe, and the maximum possible number of fatalities is not affected by any finding.

The author notes that resources for the reduction of risks to the public are not infinite. At some point, a greater improvement in health and safety is to be expected from a more stable and viable economy than from a reduction in pollution or the rate of accidents. Studies might enable a reasonably accurate evaluation to be made of a proper level of expenditure for risk reduction. Within such a level of expenditure, if we fail to devote our resources to those risks in which the most reduction is achieved per dollar, we are not optimizing the effect of our capital outlay. Of course, inequities must be avoided; no individual should be knowingly left exposed to a risk significantly greater than some upper level of acceptability. In establishing such parameters it must be remembered that each individual or group that makes recommendations or otherwise takes actions affecting national priorities bears some responsibility for any adverse effects.

The question "How safe is safe enough?" is difficult for society to address. Approaches might include (1) nonintervention (rely on the marketplace); (2) professional standards (rely on the technical experts); (3) procedural approaches (muddle through); (4) comparative approaches (reveal or imply preferences); (5) cost-benefit analysis; (6) decision analysis; and (7) expressed preferences (rely on public perception of risk). Quantitative risk-acceptance criteria could play an important part in any program developed from such approaches.

Paykel, Eugene S.; Brigitte A. Prusoff; and E. H. Uhlenhuth. 1971. Scaling of Life Events. Archives of General Psychiatry 25:340-347.

This article describes a study in which varied subjects were asked to judge, on a numerical scale, the degree to which particular life events were upsetting.

Methodology in the study of life stress has been slow to develop. One deficiency arises from the infrequent application to life events of techniques for quantification. Scaling in social and behavioral sciences, while less precise than in biological and physical sciences, has received considerable attention. The difficulty in quantifying life stress stems from the fact that life events are complex and multi-faceted so that apparently identical occurrences may differ importantly in many details. Even identical events may carry different implications for different individuals, depending upon psychological makeup and previous experience. Additionally, stress is not a directly observable phenomenon; it can only be inferred from the individual's subjective feelings following the event or from other observable behavioral or somatic phenomena.

A varied sample of 373 subjects were asked to evaluate events in terms of how much distress or "upset" they provoked, using a 0 to 20 equal-interval scale without any event being fixed in value. The list of life events contained 61 items and was derived, with considerable modification, from one developed by Holmes and Rahe in 1967. Modifications included substitution and rephrasing of items to make them more suitable for lower socioeconomic class subjects and elimination of some items that might have reflected psychiatric symptoms. Other items which appeared to contain diverse events were split into their components; for example, separate items for promotion and demotion were derived from the original "change in work responsibilities" item. The subjects for this study were 213 psychiatric patients and 160 relatives of patients at two facilities, one in Connecticut and the other in Illinois. Psychiatric patients who were too disturbed to cooperate were excluded from the study as were a small number of subjects who were too illiterate to read the questionnaire. A self-report symptom scale, the Symptom Distress Checklist, was also administered to patients, but not to relatives; the results are not presented in this article.

The mean scores for the 61 events ranged from 19.33 for death of a child to 2.94 for having a child marry with approval. Heading the list were events expected to be of major proportions--death of a child, death of a spouse, being sent to jail, serious financial problems, being fired, miscarriage or stillbirth, and more. The low-scoring events appeared to be of two kinds. Some were desirable in quality, such as the marriage of a child with the respondent's approval or becoming pregnant when wanting a baby. Others appeared to be relatively trivial, implying little in the way of either life change or undesirability, such as a move within the same city or minor somatic illness. Considerable discussion is given to aspects of the study such as variability of scores, consistency over sociodemographic groups, methodologic differences, and comparison with the Holmes-Rahe Scale. For this scale to be suitable for a wider application there must be at least moderate consensus between individuals as to the perceived stressfulness of events. Results indicate a moderate variability with respect to individuals (standard deviations of event judgements ranged from 2.21 to 6.05; most were between 4 and 5.5). Six sociodemographic variables were examined--age, sex, race, marital status, religion, and social class. Agreement across groups was very high. Differences on methodologic variables was somewhat more pronounced but seemed to involve consistent effects. Overall the authors' scale agrees with that of Holmes and Rahe moderately, in broad outline, but differs in detail. Holmes and Rahe focused more on life-change adjustment, which emphasizes change in lifesyle and adaptation. The authors focused on the concept of upset, which is concerned more with the subjective distress caused by the event and involves questions of life change value and desirability. In this study, the events scoring high tended to involve both change and undesirability while those scoring low appeared to imply little of both undesirability and life change or to be desirable in quality while necessitating moderate change. The possibility that recent occurrence of the event might distort scaling was investigated, revealing a relatively weak tendency for recent experience of an event to magnify its perceived importance.

Portney, Paul R. 1981. Housing Prices, Health Effects, and Valuing Reductions in Risk of Death. Journal of Environmental Economics and Management 8:72-78.

The author offers a methodology for the derivation of risk valuations for certain environmental risks by combining conventional property-value studies with epidemiological or mortality studies.

Using data from a study of the effect of air pollution on the value of single family dwellings in Allegheny County, Pennsylvania, and an EPA study of the effect of air pollution on age- and sex-specific annual mortality rates in the same county in the same period, risk valuation may be estimated by the following equation:

$$Vr = \frac{dV/dQ}{dR/dQ} - M, \quad \text{where} \quad M = \frac{Va \dfrac{dA}{dQ}}{\dfrac{dR}{dQ}}$$

where

Vr – the additional amount people will pay for dwellings that expose them to a lesser risk of death from illness related to air pollution
V – the value of a given dwelling
Q – air quality
R – the risk of death from air pollution-related illness to which residence in the given dwelling gives rise
M – approximation of the implicitly revealed equilibrium valuation of reduced risk

Sulphur dioxide is used as a measure of air quality in both the property value study and the mortality rate study, total dustfall is used as a second measure in the property value study, and total particulate concentration is used as the second measure in the mortality study. Families were assumed to consist of a 40-year-old couple with one child; the reduction in air pollution was assumed to benefit all family members.

The total risk reduction to a household was calculated to be 0.00024, and the housing price differential necessary to "purchase" that air quality improvement was estimated to be $335 (which represents an annual cost of $34 at an interest rate of 10 percent), so that a household willing to pay the monthly premium for that reduction in its annual risk exposure is implicitly valuing a statistical life at $142,000. A 42-year-old male paying $34 annually to achieve a risk reduction of 0.00009 would imply a valuation of $378,000. Older individuals purchase greater risk reductions for the same housing price differential, resulting in a lower implied valuation of statistical life.

The author notes that (1) the risk valuations given only represent low-level, marginal risks; (2) it is improbable that the sample households were fully aware of the specific effects upon human health of the pollutants in question; (3) it is unclear whether the households had good information about air quality differentials between neighborhoods, although the significance of the air quality variables in the property-value study suggest that they did; and (4) if the effects of other benefits resulting from air quality improvements (e.g., lower cleaning bills, aesthetic appeal) are very great, then the risk valuations may be overestimated.

Rahe, Richard H. 1968. Life-change Measurement as a Predictor of Illness. Proceedings of the Royal Society of Medicine 61:1124-1126.

The author examines the possibility that subjects' life-change estimates alone can be used to predict the distribution of future disease in a population and future experiences with minor as well as major illnesses.

The sample consisted of approximately 2,500 enlisted men and officers aboard three U.S. Navy cruisers, two of which were deployed to Vietnam and one to training exercises in the Mediterranean. Two-thirds were 21 or younger, and two-thirds were high school graduates. Life-change data were obtained on each subject at the beginning of the cruise, upon which predictions of near future illness distribution were made. Health-change criteria were gathered at the end of the cruise. Life-Changes were assessed using the Schedule of Recent Experience questionnaire (SRE). The various changes were weighted through the use of life-change units (LCU), numerical values assigned to each change; in this way, both quantity and quality of various life changes are assessed. Predictions were made by rank-ordering the subjects according to each subject's LCU totals for the six months preceeding the cruise. The upper 30 percent of the rank-ordering were designated "high risk," while the lower 30 percent were designated a "low risk" group.

The results show that the high risk group consistently reported more total illnesses for each month of the cruise period. The high risk group reported 30 percent more illnesses over the follow-up period than did the low risk group. For each month of the cruise, the high risk group had more illness severity than did the low risk group, with 30 percent more illness severity among the high risk group during the follow-up period. Life-change data accounted for a small portion of the variance. Other important factors were Black race, young age (17-18 years of age), anxiety over health prior to the start of the cruise, and working in certain environmental conditions aboard ship. The timing of illnesses was found to be related to major changes in the ship's schedule of operations during the cruise.

Roberts, Blaine; Jerome W. Milliman; and Richard W. Ellson. 1982. <u>Earthquakes and Earthquake Predictions: Simulating their Economic Effects</u>. Technical Report Prepared for the National Science Foundation under Grant PFR 80-19826.

This report summarizes advances in methodology to estimate the regional economic impacts of earthquakes and earthquake predictions. A regional economic model is proposed which accounts for (1) supply-side constraints; (2) the potential use of new and currently unused technologies; and (3) the decisions by firms and households to relocate in response to an event or a prediction. The regional econometric model is used to establish a baseline against which the effects of an earthquake could be measured. Three simulations were conducted to determine the impact of an unanticipated disaster. The simulation results, in the form of aggregate regional effects upon population, employment, and personal income show that the regional economy is resilient and that recovery is assured even in the event that pessimistic assumptions are employed. According to the authors the key to recovery lies in national growth factors which drive regional economic conditions. Losses are shown for the region as a whole and also for each of the three counties. Capital losses are prove to dominate regional income effects. The rationale offered for this finding is that recovery from the event, i.e., investment in new buildings and equipment causes a multiplier effect which tends to mask the effects of the disaster.

The report underscores several findings important from the standpoint of the emergency water problem. The regional losses may be different than national losses due to the fact that production gains in other regions can offset or substitute for production losses in the region hit by the disaster. The authors go on to argue that if regional production is not capable of being substituted by production in other regions then national production may not make up for regional losses. It may even turn out that production elsewhere drops due to the lower availability of an "essential" product. Therefore, they strongly recommend against tying a regional input-output model to a national input-output model. To do so would imply that the coefficients are fixed and that no substitutions are possible; this may prove to be incorrect.

The report represents an important contribution to the literature in that it changed the way in which economists looked at secondary losses. It questioned the use of fixed interindustry coefficients to model disaster shocks; it identified the potential for double counting losses (both damage to industrial capital plus the income which that capital yielded its owners); and it provided a foundation for discussing the difference between regional and national losses. On the negative side, it promised to employ a "process model" approach to predicting how industries would respond to supply shocks. It appears that the strategy proved to be more time consuming an challenging then the authors originally thought. The partial success they report could be interpreted to mean that the approach is theoretically superior but not as practical from the standpoint of data requirements and difficulty in terms of its implementation.

Salkin, Lawrence E., and Debra A. Lindsey. 1986. The Use of Microcomputers to Assess the Impacts of the Earthquake/85 Exercise. Working Paper, Federal Emergency Management Agency.

This paper reviews the results of FEMA's Earthquake/85 Exercise as it pertained to the impacts of water systems on the regional economy. The exercise was conducted to determine the effectiveness of regional and national plans in coping with a disaster of major proportions.

A regional economic analysis was performed using an input-output database (IMPLAN) for five California counties. The scenario which formed the basis for making projections regarding the economic impact was reported as follows:

> . . . The catastrophic earthquake was simulated to have occurred at 09 30 P.D.T. June 17, 1985, in the Southern San Andreas fault region between Gorman and Palmdale north of Los Angeles, causing a surface fracture nearly 150 miles long. . . . The earthquake measured 8.3 on the Richter scale and lasted for 45 seconds. Initial casualty estimates were 5,000 killed . . . The catastrophic earthquake and aftershocks caused severe damage to medical, transportation, energy, water, communications, and sanitation systems . . . (p. 2).

The authors utilize the estimated direct damages along with the interindustry coefficients provided by IMPLAN to develop a linear programming model which maximizes value added subject to the post-disaster damages (production constraints). A numerical example based on the FEMA exercise illustrates the impact of an 80 percent reduction in water availability. The model shows that nearly $55.6 billion in outside assistance would be required to provide surviving households a satisfactory level of material comfort.

The application of a linear programming model to the problem of postdisaster reconstruction is questionable. It is not clear that the economy will behave as efficiently as might be suggested by this approach. Capital, resources, and production may not move according to the shadow prices implied by the optimal solutions. On the other hand, fixed production coefficients may be overly constraining. Input-output statistics, on which the linear program is based, reflect the long-run steady-state tendencies of the economy; in all likelihood the intra and inter tradeflows would adjust during the recovery period, a factor which a programming solution such as this cannot reflect. Most important, the estimates of economic loss presented in the paper are, as the authors admit, hypothetical. It would be surprising, however, if a classified version of this paper did not exist somewhere in FEMA.

Wright, James D.; Peter H. Rossi; Sonya R. Wright; and Eleanor Weber-Burdin. 1979. After the Clean-up: Long-Range Effects of Natural Disasters. Beverly Hills: Sage Publications.

Wright et al. focus on the question: Does occurrence of a disasters alter the path of a community's economic growth, i.e, might the damages cause secondary effects which are detectable in secondary census data, specifically housing starts? Data were collected on approximately 10,000 events which occurred over the decade of 1960 to 1970. Simple regression analyses were performed to determine whether the so-called disaster-stricken communities suffered any lingering effects when compared with a randomly selected control group. The statistical analyses proved conclusively that no long-term impacts resulted.

The average tornado included in Wright et al. study destroyed a mere three homes, hardly enough to tax even a small community, let alone a major metropolitan region. There are several other reasons for discounting the importance of these findings. Their conclusions are based on expected values, which is hardly an appropriate measure for a risk assessment. Second, it is a mistake to equate eventual recovery with the absence of secondary effects. The secondary losses are summed from the point when the disaster occurred to the time when recovery has been achieved. Last, the Wright et al. argue that the provision of disaster assistance dampens the disaster's effects, thereby speeding recovery.

This highly provocative study tended to be misread. It was relatively easy to wrongly conclude that the results showed no secondary impacts. Wright et al. were careful to point out that even though "We find no discernible effects of either floods, tornadoes, or hurricanes on changes in population or housing stocks experienced by counties in the period between 1960 and 1970" (p. 24), there are several reasons for this finding. "First, the damages and injuries directly attributable to the disasters are very small in relation to the population bases and housing stocks of the counties involved." "Second, disaster policies on the federal, state, and local levels in effect during the decade of the 1960's have been sufficient to provide enough additional support for reconstruction to dampen considerably the lasting effects of natural disaster events on counties."

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